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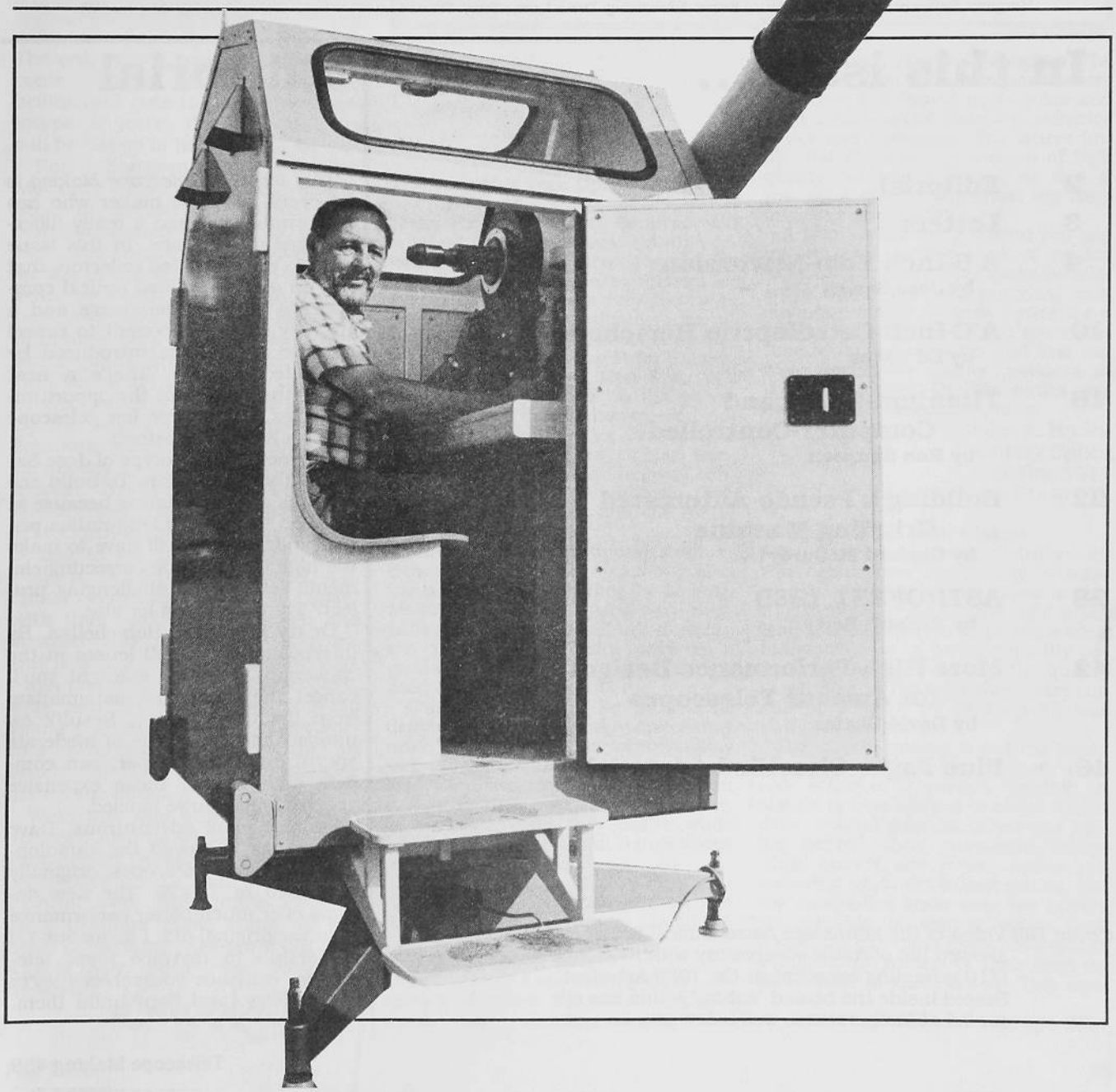
The magazine *for*, *by*, and *about* telescope makers!

Fall 1989



Telescope Making #38

The magazine *for, by,* and *about* telescope makers!

Editor: Richard Berry
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Cover: Bill Volna of the Minnesota Astronomical Society showed his portable observatory with its 6-inch f/10 refracting telescope at the 1989 Astrofest. Seated inside the heated "cabin," Volna has observed at temperatures well below zero.

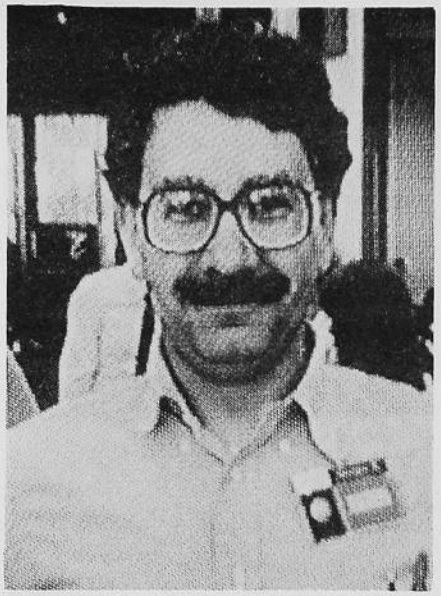
Editorial

This issue of *Telescope Making* is for every telescope maker who has ever wanted to build a really different type of telescope. In this issue are two unobstructed reflectors that rely on a slightly tilted optical components to form the image and a strongly tilted component to cancel out the aberrations introduced by the tilted primary. That's a neat idea. Plus you've got the opportunity to go where very few telescope makers have gone before.

I've seen the prototype of Jose Sasian's Yolo-Newtonian. To build one requires a certain daring because in addition to the easy long-radius primary mirror, you will have to make the highly astigmatic correcting element. You want a challenging project? Try this one on for size.

Or try Ed Jones' Herschelian. By interposing two small lenses in the converging beam of starlight you'll cancel the coma and astigmatism from the tilted mirror. Result? An unobstructed telescope of moderate aperture that, on paper, can compete with one of those expensive apochromats you've fancied.

For the more adventurous, Dave Shafer has improved the catadioptric family of telescopes originally presented in *TM#29*. The new designs offer much better performance than the original did. I invite our *TM* readership to raytrace these telescopes, convince yourselves they're worth a try, and then build them.



Please note that
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The only way a paper telescope become real is for someone with brains and guts to construct a prototype. If you're that person, Dave will be happy to help you all he can.

Ron Simpson and Gaylord McCurdy have explored another area of novelty: automated and semi-automated machines. Ron's computer-controlled telescope really works; at the Winter Star Party last year, we used it to find and compare very red stars from a list of coordinates. Lots of fun to make, and Ron's plans are complete enough that you don't have to be a genius in electronics to build his circuits. By the way, I have listings of both computer programs and can mail a photocopy to anyone who wants to inspect the program's logic but doesn't need a tape from Ron.

McCurdy's grinding machine appealed to me because years ago I built a Draper-type grinding machine. I remember the hours I spent with that beast as it groaned and creaked and ground my mirrors. But it was a love-hate relationship. I was tied to a three-minute cycle of wets, and terrified that my pitch lap would grab and fling one of my mirrors to the floor. Imagine writing an article for *TM* as your machine makes the optics...

Well, just one quick word about Voyager. Anyone who's seen the November and December issues of ASTRONOMY knows that the last few months were busy ones for me. TM's deadline came right on the heels of Neptune. Kee-runch! It was a great flyby, though, and worth all the sweat.

Richard Berry

Letters

Documenting Poor Optics

Dear Richard/ Peter Ceravolo did what all amateurs should do whenever possible: present photographic evidence of questionable equipment or its performance. I am very happy to see that amateur astronomers are finally becoming educated consumers.

Letters by people like Peter Ceravolo, John Brooks and Don Scott call our attention not only to the prevalence of poor quality commercial optics, but also to the fact that what is at stake are consumer rights. Amateurs who have hard evidence of consumer fraud should address their grievances to lawyers and the Better Business Bureau.

One reason for an apparent abundance of poor quality optics is probably the fact that it worked for so long. Making optics for a living isn't easy. Let's face it: If you could sell a mediocre mirror for the same price as a good one, would you bother making a good one? It's human not to.

Concern, expressed by some, that demands for better quality optics may drive the prices higher are probably well founded, but, higher prices may also stimulate more people to return to figuring their own mirrors and lenses to the quality they desire while learning all the beautiful things about optics!

Mladen Vranjican
232 Carrie Drive
Franklin, VA 23851

$2000 Too Much To Pay

Dear Richard/ I am writing you in response to recent *TM* letters concerning the quality of commercial Newtonian optics and elliptical flat optics. The letters are from amateur astronomers who have purchased poor optics and from a commercial source of refractor optics and telescopes. The letters imply that there are no sources of high quality Newtonian optics, or that if you want quality you must dig deep into your pocketbook.

It is true that you get what you pay for—but not to the tune of paying $2,000 for a 12-inch paraboloidal telescope optic. You can purchase outstanding quality 12-inch optics for a fair price ($600 or so) if you spend the time to do the research and find out who makes the quality products at the right price. Quality optics are available for reasonable prices.

John A. Hudek
Galaxy Optics
P.O. Box 2045
Buena Vista, CO 81211

Makers: Honor Your Claims

Dear Sir/ I am greatly disturbed by this debate over the quality of commercial optics. It seems no one is putting their finger on the the right problem. If a firm desires to produce what many consider to be poor quality optics, what is the harm? If the quality is reflected in the price then there can still be a place for optics with less stringent tolerances.

But optical quality is not the issue. The issue is deceit. If a company does not produce a certain quality, it should not be allowed to claim that it does. Optical manufacturers are hiding behind their guarantee policy. Sure, buyers can return optics not measring up to advertised claims, but the companies know very few buyers are capable of testing optics (and those that can most likely have waited a significant portion of their lives for the arrival of their order). This con-

Continued on page 38...

Building a 6-Inch Unobstructed Yolo-Newtonian

I have designed an optical system that can be thought of as an unobstructed Newtonian telescope. This system uses a standard paraboloidal primary and a small secondary mirror. In this telescope, however, the secondary is not flat but is concave and cancels the aberrations introduced by the tilted primary; the resulting image quality is good as long as the primary is slow.

The optical system can also be considered an extreme case of a Yolo; therefore the formulas given in "How To Design a Yolo Telescope" (*Telescope Making #37*) can be used to predesign it. Because the tilt of the secondary is quite large, it is necessary to optimize the predesign using ray tracing software.

My design uses a 6-inch f/12 paraboloidal primary. The characteristics of the system are given in the table with the same notation used in "How To Design a Yolo Telescope." The field performance was evaluated using spot diagrams for the on-axis image, and five positions around a semifield of view of 1/4 degree. The field is limited by about 1/2 wave of linear astigmatism, and the image plane is tilted 8 degrees. The image anamorphism is 1.4 percent.

TMs who do not have access to a computer still can design their own unobstructed Newtonians. This can be done by optimizing their predesigns using my optimized design as a guide. To do this, design my system using the formulas given, estimate the percentage error, and then correct the design.

The correction is first applied to the secondary angle of tilt, then to the secondary long radius of curvature. The correct setting of these parameters make the secondary cancel the on-axis coma and astigmatism produced by the primary. This method will work provided the systems considered are similar to my design, say, for systems using a 6-inch primary with a focal ratio between f/10 and f/14. Scaling can also be done to specify smaller systems.

It must be remembered that minor adjustments to correct residual on-axis aberrations due to fabrication errors and slight calculation errors can always be done after the optics have been made. These adjustments are done changing the secondary position and tilt.

Making the Secondary

The surface of the secondary mirror is a section of a concave oblate ellipsoid that has two principal radii of curvature. The first step to make the mirror is to grind a long radius of curvature sphere. Because the difference in the radii of curvature, R_s and R_t is large, the double curvature must be generated during the last stage of fine grinding. For this purpose, long unidirectional grinding strokes are performed with the mirror on top of a full-sized grinding tool. This shortens the mirror's radius of curvature in the chosen direction.

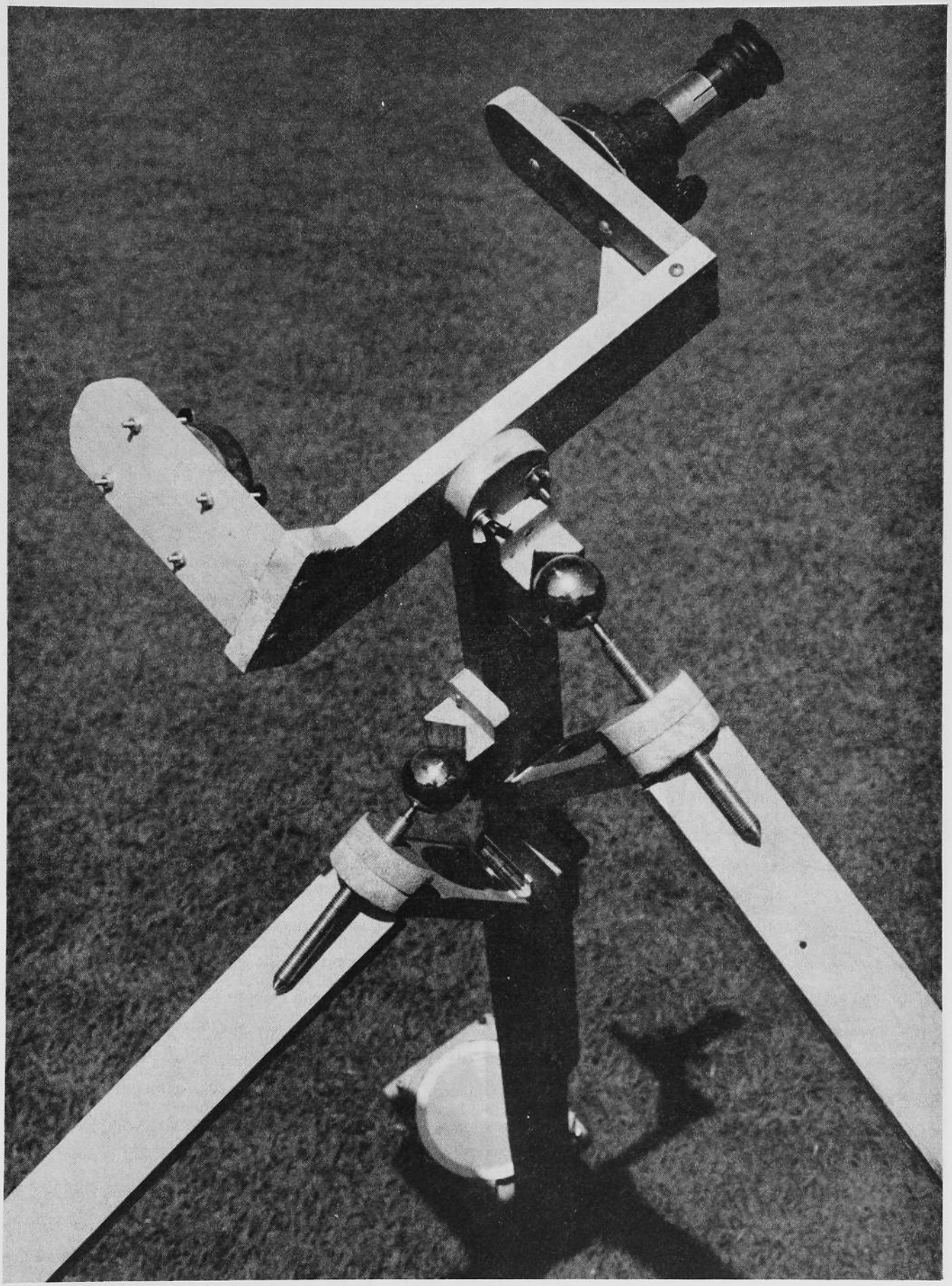
This process is very similar to traditional grinding except that the well-known sequence of events happens unidirectionally. Namely, a deep excavation in the center of the mirror is made using a long stroke, and then the rest of the surface is made uniform in curvature by reducing the stroke length. In fact, for this surface smoothing, you can perform normal grinding strokes in all directions doing only translational movements.

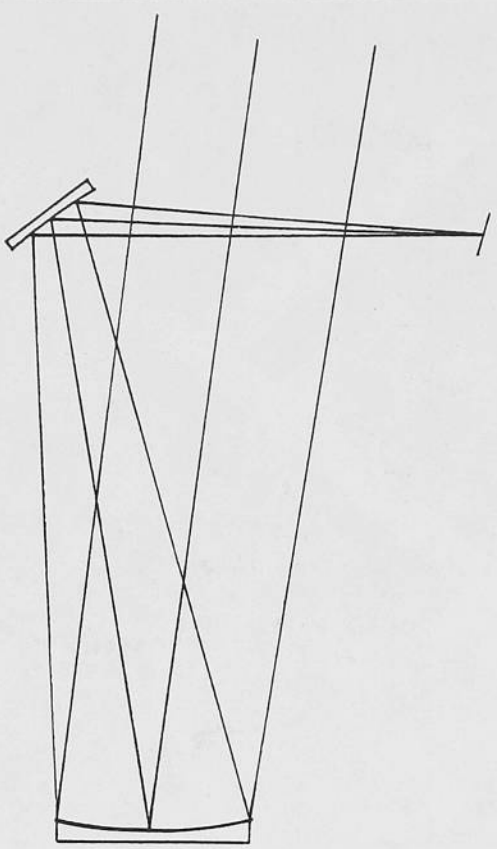
In my article in *TM#37*, I suggested a double four-bar linkage to constrain the rotation of the grinding or polishing tool, but the entire process can be done by hand. For this optical system the difference in sag of the two principal sections is so large that maintaining the parallelism between tool and mirror to within a few degrees becomes important. One can easily feel the effects of a small rotation in the grinding or polishing movements, and eventually one learns to direct his or her hands very precisely. Because the surface has two perpendicular planes of symmetry, you can rotate the mirror 180 degrees once in a while.

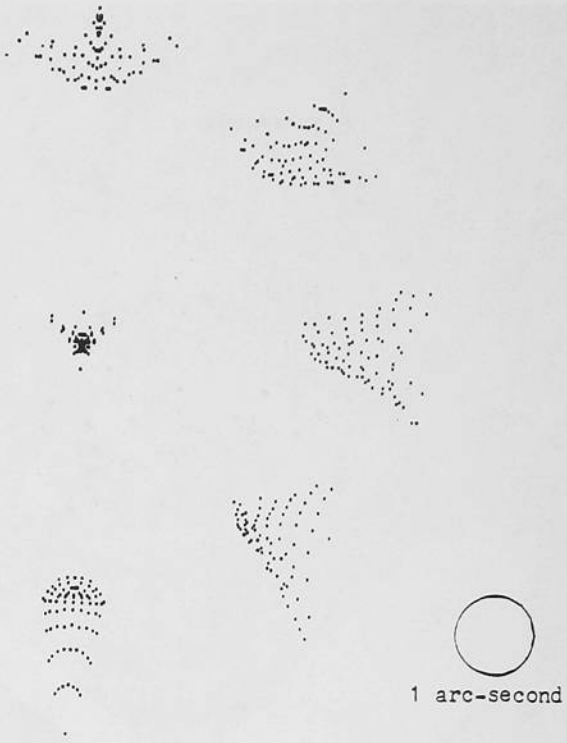
To monitor the generation process, I painted the mirror surface with a China marker, a waxy type of pencil. After removing the excess paint by scraping it with a razor blade dragged almost parallel to the blank, the surface became shiny enough to reflect light and made an optical test possible. The appearance of a ground surface before and after the scraping is illustrated in the photo.

You can null test the mirror at its conjugate focii, but I tested the secondary using the aluminized primary

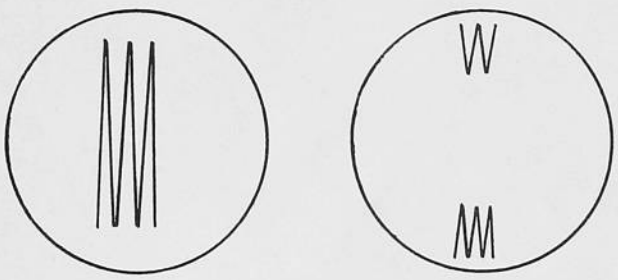
This novel optical design on its novel mounting makes for a very unusual-looking telescope. The Yolo-Newtonian offers an unobstructed aperture and an optical system consisting of just two elements.



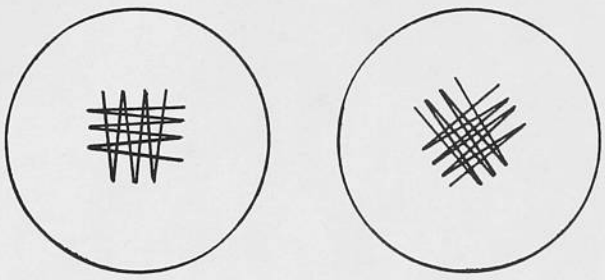




The optical configuration of the unobstructed Yolo-Newtonian produces good images over a half-degree field. Spot diagrams shows axial and 0.25-degree off-axis performance at five positions around the field.



Generating Strokes



Uniformizing Strokes

Typical generating and uniformizing strokes for secondary mirror; zig-zag lines show the path of the mirror center over the tool. Only translational movements are allowed.

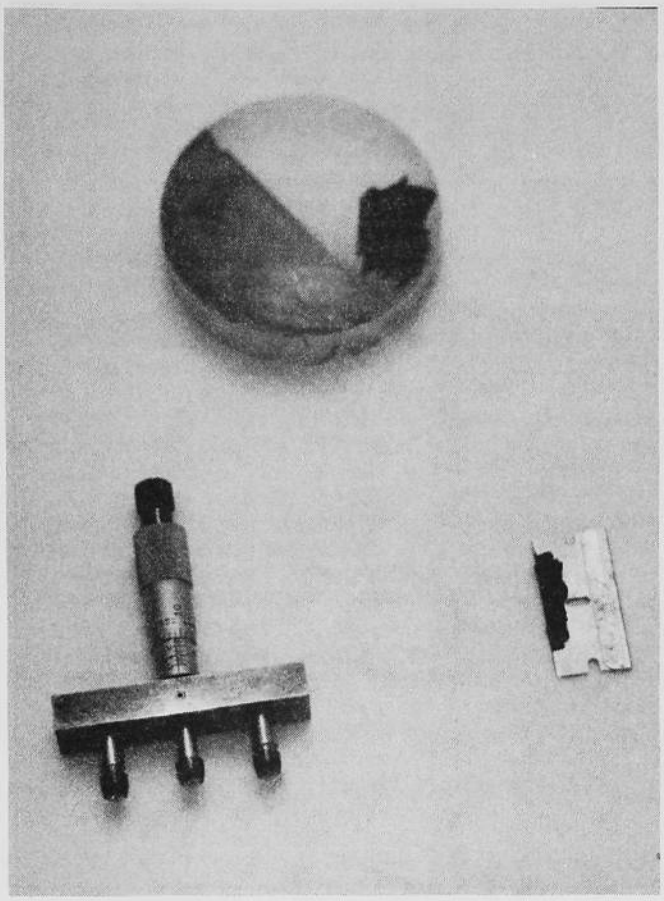
mirror. I prefer the test in which the secondary is placed at a specific angle with respect to the axis of the aluminized primary mirror because of the reduced test distances.

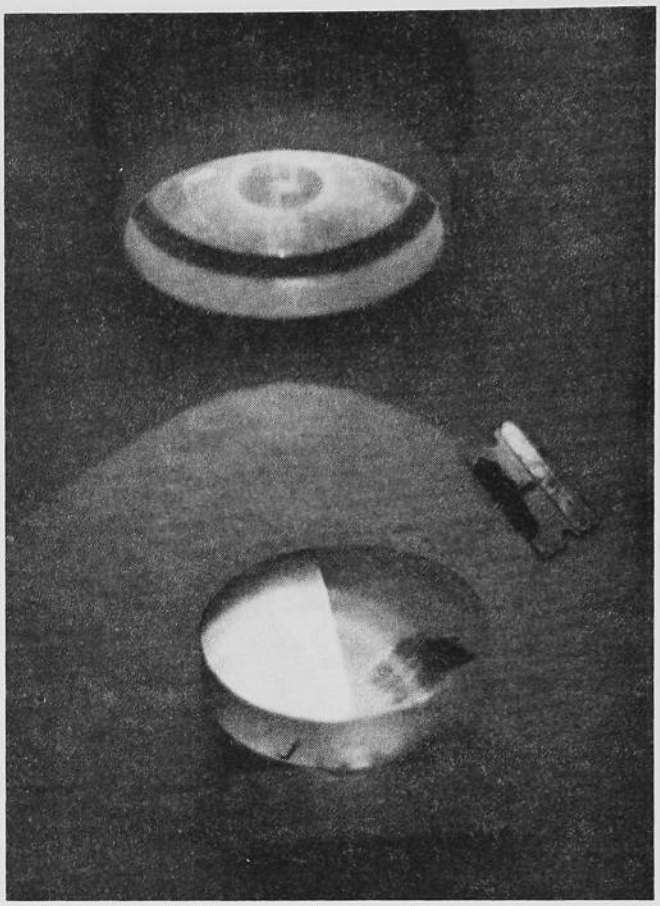
The purpose of these tests is to verify that no astigmatism is present when the secondary is tilted by the angle α, as calculated using the formula given in the above-mentioned article. These tests insure that the appropriate difference in curvature has been generated. The astigmatism can be detected by looking at the image of a point source with an eyepiece or by projecting the image on a fine ground glass.

Once the double curvature is generated, make a full-sized polishing lap and polish the secondary in a manner similar to the polishing of a standard mirror but doing only translational polishing movements. Either one of the methods mentioned can be used for the final test of the secondary. The second method using the primary is not a null test, and some residual coma will be observed. However, a smooth surface must be obtained.

The blank for my secondary is 3 inches in diameter, considerably oversized to allow for a turned-down edge. This problem could easily result if significant movements of rotation happen during the polishing. The clear aperture of the secondary is elliptical as in a regular Newtonian. The smaller diameter, that is, Φ_s, is the one used in the calculations. The large diameter, without considering the field size, is given approximately by $\sqrt{2}\cdot\Phi_s$.

The curvature of the starting long radius sphere was measured with a two-leg spherometer. The sag to measure was so small, about 0.001 inches, that a verification was necessary. This was done during the test in which the primary was used. Knowing the radius of the





primary R_p, the power of the secondary,

$$P_s = 2 \cdot \cos(\alpha) / R_s ,$$

the primary to secondary test distance q, and the secondary to test point distance s, you can find out the short radius of the secondary from the relation:

$$P_s = (1/s) - (1/(R_p - q)) ,$$

which is the well-known lens formula.

To recap, then, here are the steps you should follow in making the ellipsoidal secondary:

1. Use an oversize blank (3 inches) and fine-grind it to a sphere of radius R_t.

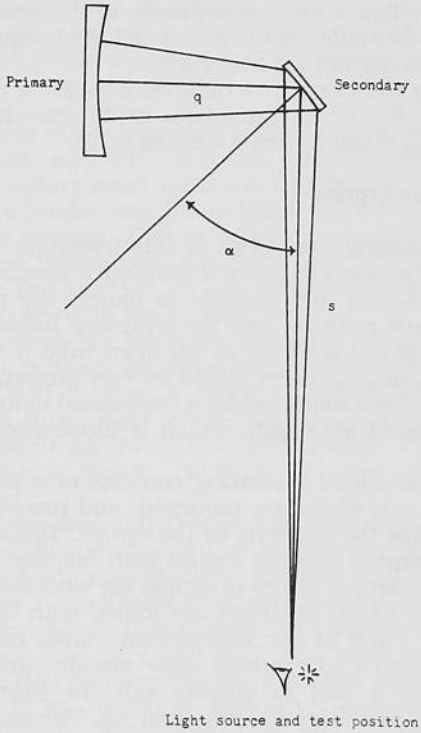
2. Grind in the short radius by doing long, unidirectional grinding strokes for 30 minutes, with the mirror on top. Occasionally rotate the mirror or tool a full 180°.

3. Uniformize the surface by doing normal-length unidirectional strokes for 20 minutes.

4. Determine the difference in radii using either method. Method 1: Measuring the sag in the two principal meridians using a two-leg spherometer. Method 2: Coat the fine-ground surface with a waxy pencil, scrape off the excess with a razor blade, and determine the angle α at which you see no astigmatism.

5. Proceed toward the correct difference in radii, by repeating steps 2 through 4, until you see the correct sag in both meridians or until you see no astigmatism at the angle α specified by the design. Make sure the surface is uniform before proceeding.

6. Polish with a full-size polishing lap using translational strokes only; do not rotate the tool or mirror.



A simple test configuration for checking the radii of the ellipsoidal secondary mirror. The long radius meridian of the secondary must lie in the plane of symmetry of the test system.

Data for Three Unobstructed Yolo-Newtonians

(dimensions in millimeters)

Focal Ratio of Paraboloid	f/10	f/12	f/14
Φ_p	150	150	150
Φ_s	40.2	33.42	28.64
t	1100	1400	1700
I_p	3.00°	2.25°	1.95°
I_s	42.0°	42.75°	43.05°
R_p	3000	3600	4200
R_s	5140	5900	5944
R_t	10252	11780	11869
b	360.2	365	365.2
α	44.92°	44.95°	44.95°
System f/number	8.97	10.92	12.75
Focal Length	1346	1638	1913
Tilt of the Image Plane	8°	8°	8°

Strokes should be normal in length; avoid long strokes.

7. Test the figure and smoothness of the secondary. Apply methods analgous to those used in standard mirror-making to correct figure errors.

Generating the curvature difference took me about 3 hours using 5-micron aluminum oxide abrasive, and polishing took 6 hours using cerium oxide.

Mounting the Optics

I started making the optics of this telescope with no idea of how to mount them. I wanted a mounting as simple as possible and decided to mount the primary and secondary mirrors and the eyepiece holder on a single wood board working as an open tube. I realized that such an arrangement would be very susceptible to vibration if it were mounted on a traditional mount, so I chose a different approach, which is illustrated in the photos.

This kind of tripod mounting consists of a principal leg on which the optics are mounted, and two auxiliary legs to stabilize the pointing of the optics. These auxiliary legs, mounted at right angles with respect to each other, are connected to the principal leg with two intermediate wood links. All these are joined with ordinary door hinges. Each of the intermediate links carries a screw that serves to produce slow motion, and each screw tip has a ball to smooth out the interaction between the screw and the principal leg. The balls also serve as knobs to turn the screws.

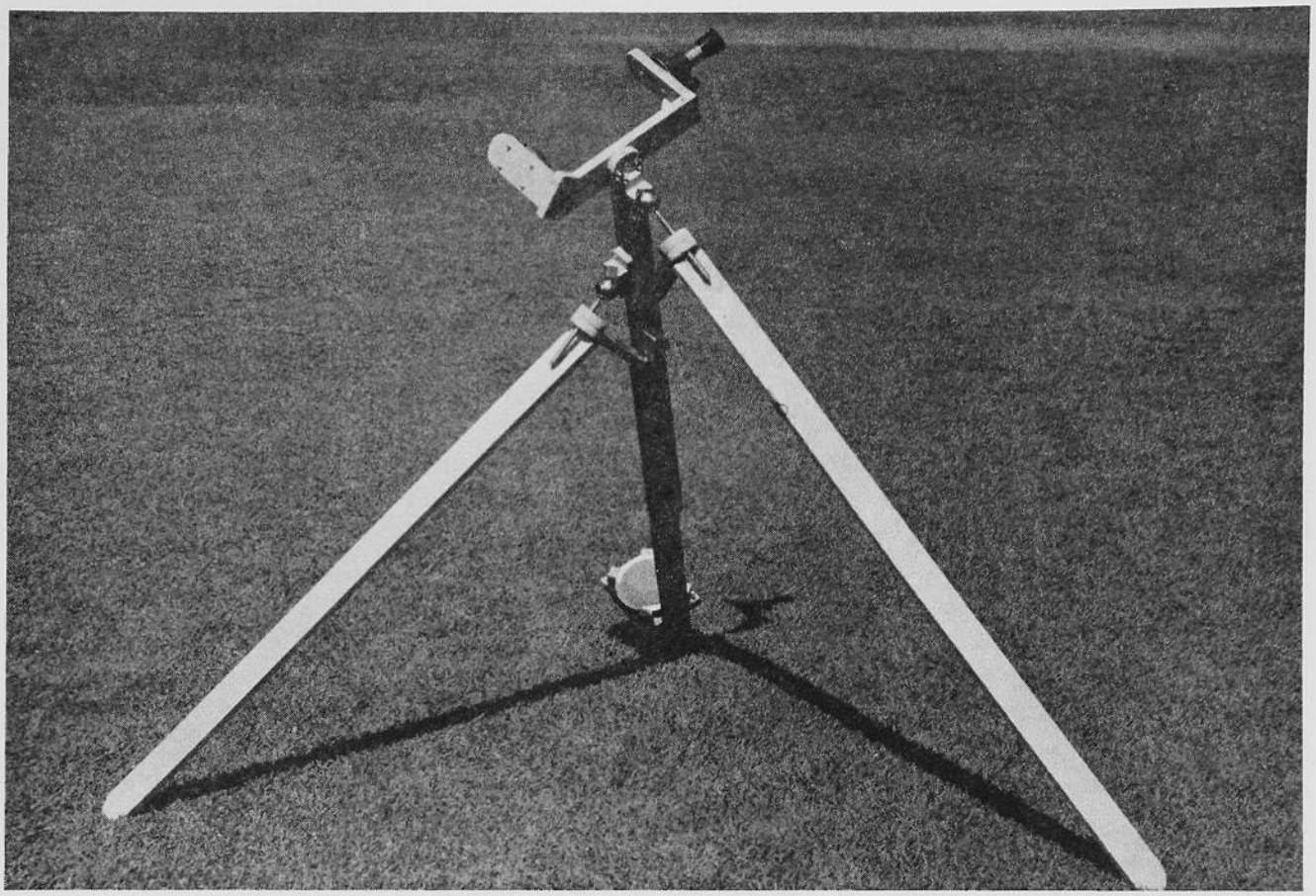
This mounting has two operational modes. In the first, called the guiding mode, the balls are in contact with the principal leg and its position is determined by the auxiliary leg apertures and screw positions. Guiding is done by turning the screws. In the second, called the aiming mode, the principal leg is not in contact with the screw balls and it is free to pivot on its lower end to aim within a limited range. The auxiliary legs follow the principal leg through the intermediate links, but they are not locking the principal leg position.

To aim this telescope the auxiliary legs are set to point the optics approximately at the desired sky object. Then, by pulling the principal leg, one goes to the aiming mode and positions the object of interest in the finder. Then the mount position is locked by bringing the screw balls in contact with the principal leg, which is done by changing the opening of the auxiliary legs. Finally, the object is brought to the eyepiece field using the slow- motion screws.

The advantages of this mounting are its great simplicity, portability, reduced weight, and most important, its inherent nature of being little susceptible to vibrations. The obvious disadvantages are that it is not an equatorial mount and its limited range of aiming. However, because the telescope is intended to observe the Moon and planets, the latter drawback is not a serious problem. The length of the auxiliary legs sets the aiming range. For my mount I can observe objects above an altitude of 45 degrees.

Telescope Alignment

Even though I made the secondary radii of curvature slightly off the nominal values, R_s was about 5,300mm, adjusting the telescope optics was relatively easy. I rotated the secondary mirror and changed its tilt to cancel the on-axis astigmatism. This operation made the defocused diffraction rings of a star circular indicat-



ing good alignment. Astigmatism varies rapidly with the secondary rotation, but the setting of this adjustment variable was not difficult because I could rotate the secondary while I was looking at the star image. It must be remembered that the meridian of the secondary's long radius should coincide with the telescope's plane of symmetry.

Coma was not a problem because it varies slowly as a function of the secondary tilt. Any coma residual will be small. The primary introduces about 2 waves of this aberration. Most of it would have been canceled by the secondary even if it were off in tilt by several degrees. However, coma varies rapidly with the primary tilt and secondary spacing, so it is important to set these parameters correctly.

When you set up your optics for the first time, follow this alignment procedure:

1. Set the primary-to-secondary distance and the tilts of both mirror as close as possible to the specified values.

2. Examine the image of a star and rotate the secondary to make sure the long radius of curvature meridian coincides with the telescope's plane of symmetry. (As the secondary is rotated, a large amount of astigmatism will be seen; rotate the secondary until no astigmatism is observed, or until any residual astigmatism is aligned with the telescope's plane of symmetry.)

3. Examine the image of a star and change the tilt of the secondary to remove residual astigmatism. You will have to move the eyepiece holder when you do this adjustment.

4. Examine the image of a star. If you observe residual coma, change the distance between the primary and the secondary slightly, until the coma is removed.

The Yolo-Newtonian optical system may be mounted in a conventional tube, if desired, on an open spar, or in a tube sealed with a precision window. If the mirrors have a smooth finish, images should be superb.

5. Carry out subsequent realignments by rotating the secondary and changing the primary's tilt. Note that the secondary must maintain its tilt with respect to the eyepiece holder and the primary mirror when you realign the system. This is relatively simple compared to first-time alignment because you will not have to change the location of the eyepiece holder when you change the tilt of the primary.

In testing the finished telescope critically, I found that the primary mirror is slightly overcorrected; therefore, I had to stop it down to about 5.25 inches to observe intra- and extra-focal diffraction rings with equal contrast. After this unfortunate discovery and subsequent repair, very good star images were observed.

After the Riverside Conference on a night of good seeing, I readjusted the optical system and could see very well, at 400x magnification, the Airy diffraction pattern of a star. This shows that very good performance can be achieved with this system. The double-double, Epsilon Lyrae, was very well split, and there was a distinct black region between the stars of both pairs.

I would like to thank Richard Sumner for providing the materials and allowing me the use of facilities to make the optics for this telescope.

Jose M. Sasian
446 North Norton Avenue
Tucson, AZ 85719

Building a 6-Inch Unobstructed Catadioptric Herschelian Telescope

After playing around with Beam-3 raytracing software, I came up with the Herschelian shown here. This telescope has a spherical primary and a meniscus corrector in the converging beam. By using a wedged corrector, the C, F, and D lines all focus to a spot 0.0003-inches diameter. I built a 6-inch version of this telescope and it performs extremely well.

I think this design has a lot to offer: it's unobstructed, has all-spherical optics, is color-free, and has only two mirrors. The mirrors can be bought commercially and the lenses are not terribly difficult to make. At f/10, however, the length of the tube probably limits the size of the telescope to about 12 inches aperture. As a cheap alternative to an expensive apochromat, I think this scope could be a contender.

The catadioptric Herschelian design is not new. After I designed my telescope, I found out that it is similar to one designed by Richerd Buchroeder. Because the corrector in Buchroeder's design isn't wedged, however, it shows residual color errors. Buchroeder obviously anticipated the difficulty of making a wedged corrector and stayed away from it.

After I *built* my telescope a friend gave me a reprint in which the British amateur J. S. Hindle describes a 12-inch Herschelian he made based on specifications given by Maksutov (*Journal of the Optical Society of America*, volume 34, page 270, 1944). This appeared in the February 1953 issue of *S&T*, so I guess I really did reinvent the wheel. Hindle's design is very much like mine except for the choice of spacings, but a number of different combinations are possible. My design is not an off-axis section of a Maksutov, but this difference is minor.

Anyhow, after studying the problem of how to make a wedged corrector, I came up with three possible ways: 1.) Generate a concentric shell and trepan off-axis segments from it. Nice for a group project maybe, but the method requires a large blank. 2.) Generate the wedge directly into the blank by tipping the first side while generating the second side. I tried this and soon realized just how difficult it is to do. 3.) Split the corrector into an equiconvex and biconcave lens and decenter. Both lenses would be concentric and you could use the concave lens to test the convex lens by interference.

I selected the third method. Although I had access to an optical shop, fabricating and testing these lenses is not particularly difficult. Advanced TMs should have little problem making them, but this design is probably not for beginners.

Making the Optics

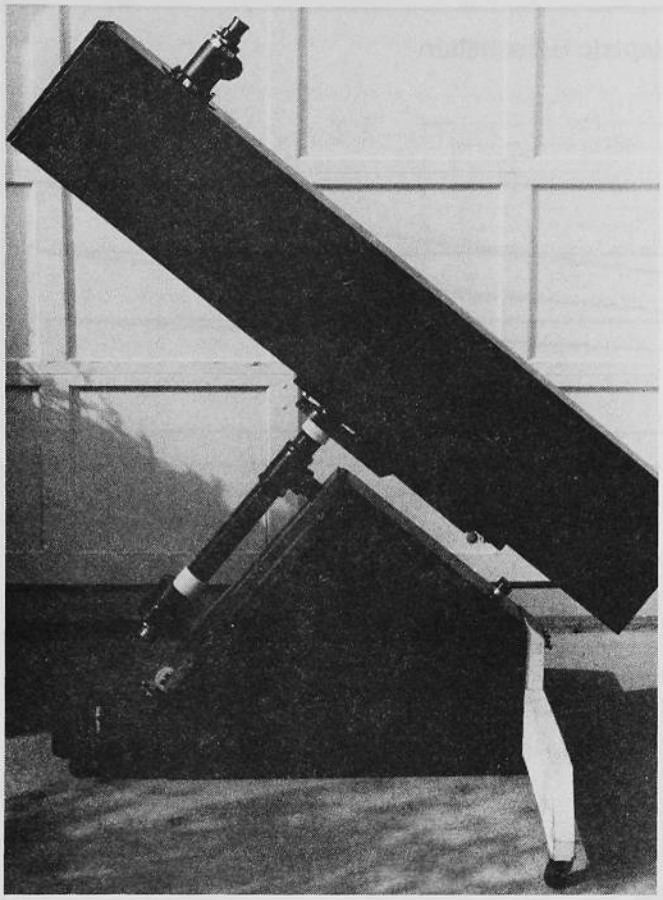
I had access to an LOH curve generator and generated the primary and both lenses on it. The primary was finished by usual mirror-making techniques and tested with a Foucault tester. I used cerium oxide to polish it and finished with Opaline, a cerium compound with a very fine particle size. The only difficulty I had was getting good contact, which I fixed by scratching grooves in the pitch facets with a razor blade. This is similar to pressing netting into a lap. I was then able to get a nice smooth null on the surface, but the radius came up 1 inch short so I had to re-optimize the system design for the new radius.

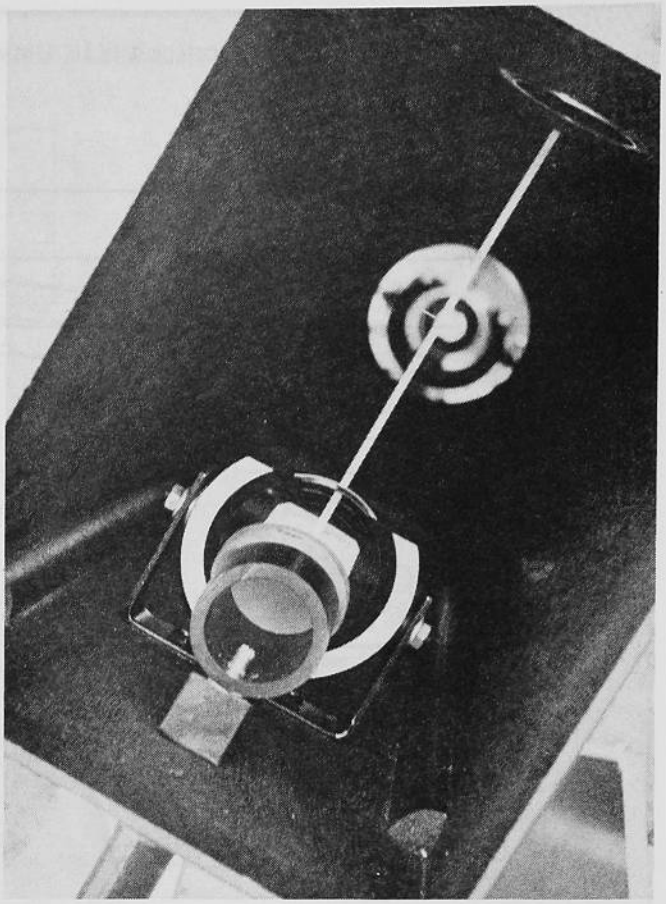
It was necessary to remove 0.010 inches of stock on the convex lens and 0.020 inches from the biconvex lens. I cut an aluminum lap on a lathe for the other concave curve (R2) and lapped it down to the finished center thickness (CT). To measure the radius on each lens, I used an electronic spherometer. The center thicknesses of the individual lenses are not critical, but their sum should be within 0.003 inches of the design value. Just as in a Maksutov, the radii should be held as accurately as possible; and if you're off slightly on one curve, the other curve should be off the same amount. When polishing, I used the concave lens as a lap for the convex lens. I then polished each surface by machine with cerium oxide and finished with Opaline.

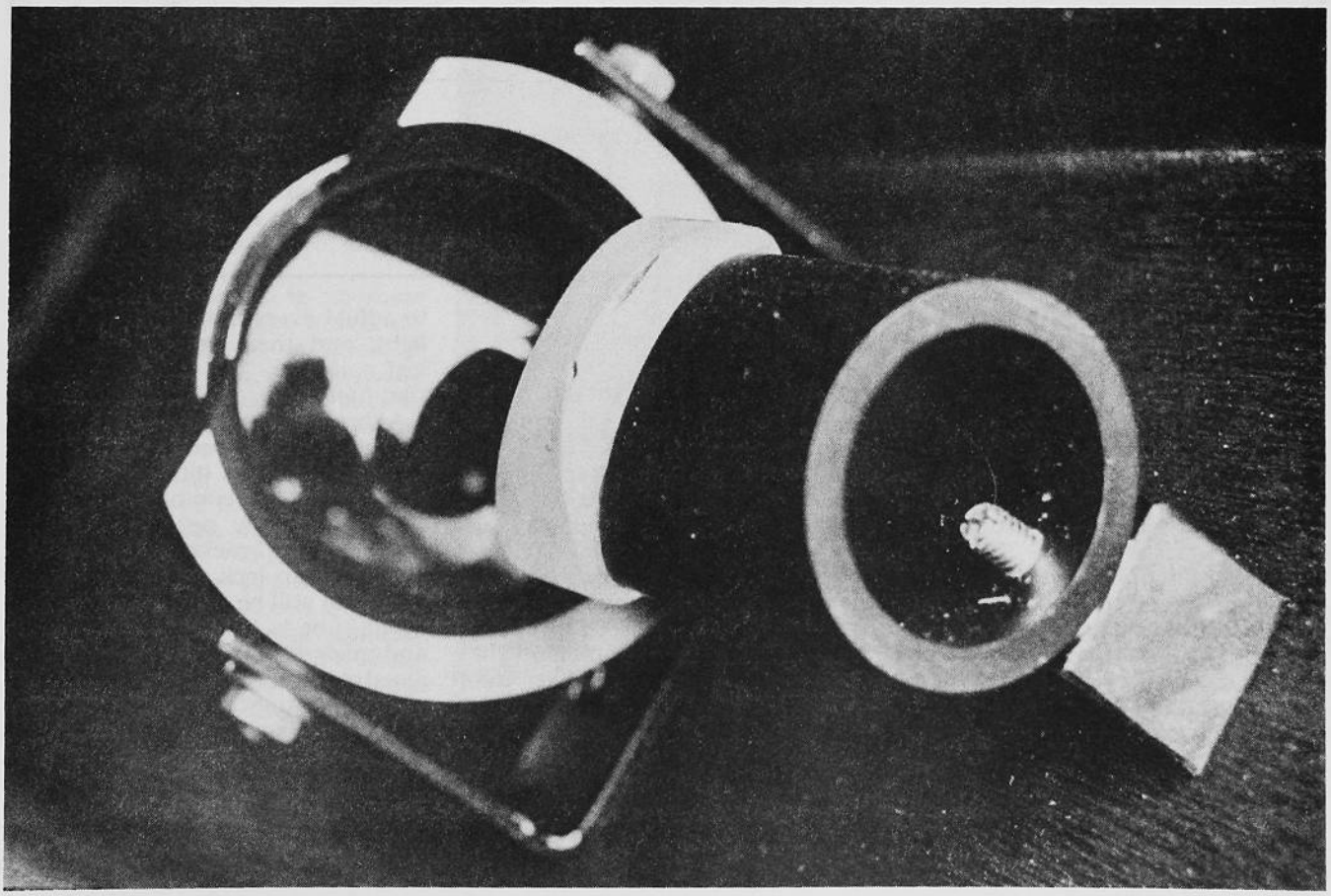
A peelable plastic film was used to protect the other side while polishing. The two outer surfaces were worked by hand to a 1/8 wave using a Zygo interferometer. (Because both curves on the convex lens are the same as the inside (cemented) curve on the concave lens, you can interference test it against the concave if you don't have access to a Zygo. The concave lens could be Foucault tested through a microscope objective or just by using a fiber optic.) The lenses were then edged by machine to the finished diameter.

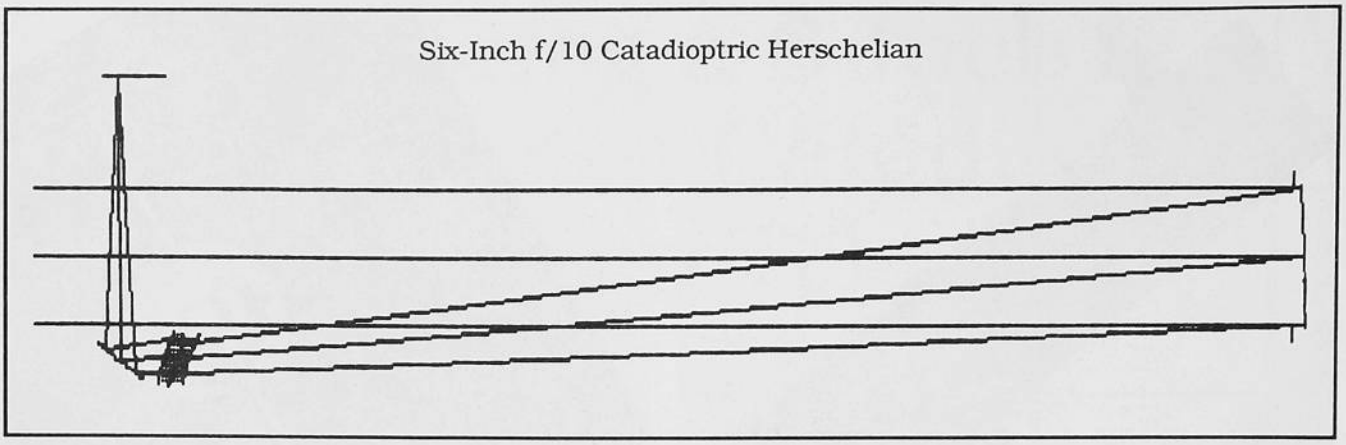
During testing with uncoated lenses, I noticed that the sky reflects off both the convex surface and the diagonal to the eyepiece. Moving the eyepiece holder to the other side of the tube and moving the diagonal farther up the tube would eliminate this reflection, but the lenses should be coated even if

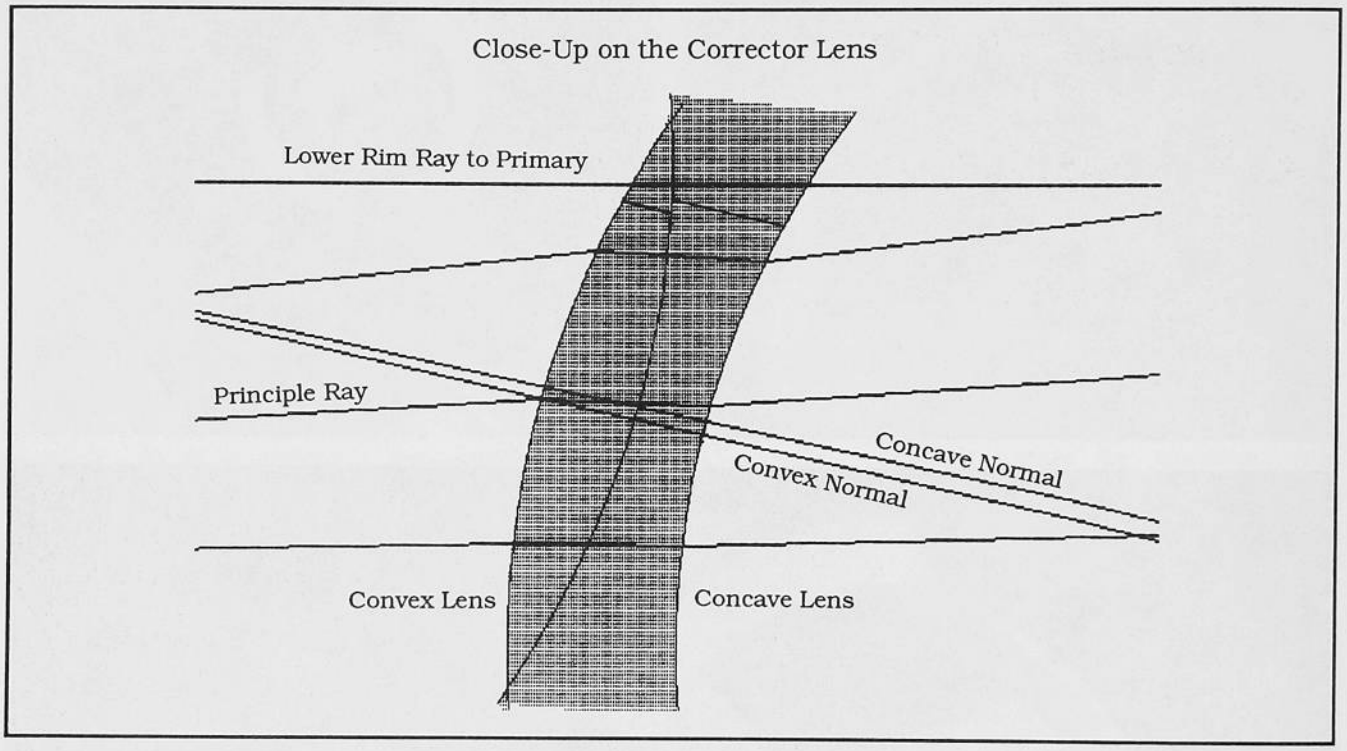
The tube of the Herschelian "Cat" is rectangular in order to accomodate its angled optical path. Alignment is accomplished with a pin-stick.











it's not required.

Mounting the Optics

The next problem was a means of mounting the lenses so that they could be decentered in one direction only and then tilted. I solved this by machining a cell out of aluminum with a bore for each lens. To insure that it wouldn't obstruct any light, I sawed the top off the cell. One problem that took me by surprise was that after the sawing -- which opened the cell -- the diameters were reduced by 0.010 inches because of stress in the metal. I had to re-edge the lenses to fit the cell.

With a milling machine I milled the bore for the concave lens so that the lens could only be moved up but not laterally. A 1/4-20 hole was tapped at the bottom for a setscrew to push the lens up.

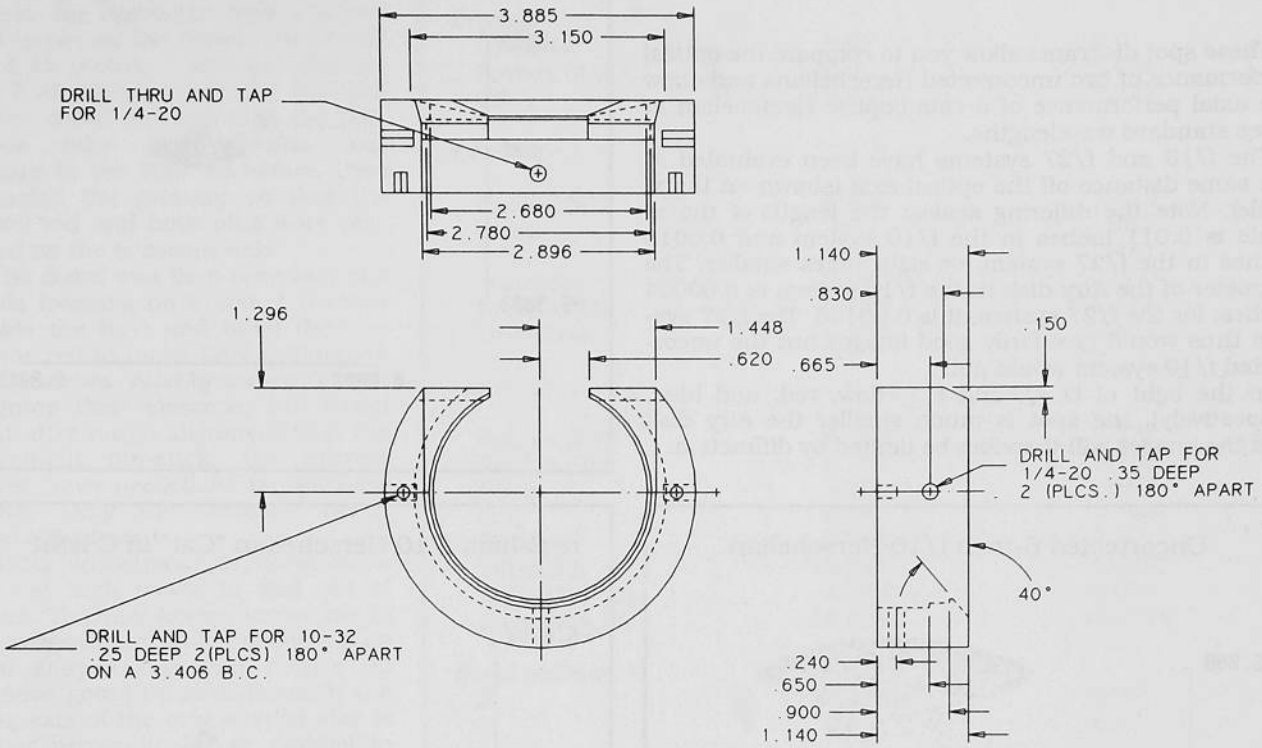
I glued two 1/8-inch-square by 0.6-inch-long blocks to the top of the milled flat to hold two leaf springs after the finished cell was anodized. The springs keep the lens pushed against the setscrew. For testing and setting up the system, I "cemented" the lenses with silicon optical grease. The decentration of the concave lens is thus controlled by the setscrew.

However, I don't recommend that you use silicone grease rather than a permanent cement because after 2 or 3 weeks it will wick out onto the surfaces. Cement the lenses with optical cement. Because both lenses are the same material, thermal expansion won't be a problem. A UV-setting cement will allow you to adjust everything, zap it with UV light, and then dispense with the leaf springs -- but I hesitate to do that just yet.

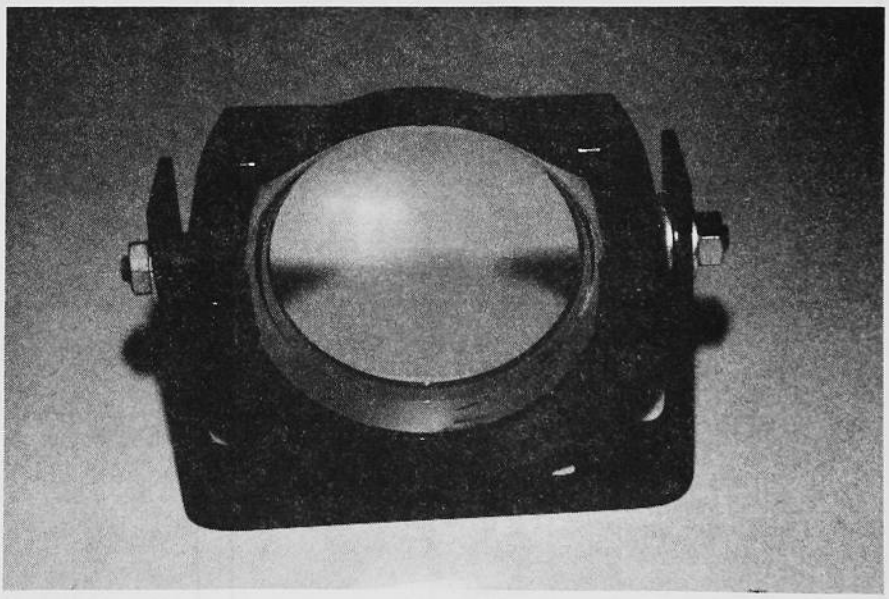
A bracket holds the whole lens cell at each end and allows it to be set to the correct tilt angle. I made the bracket by bending 1/8-inch by 1-inch steel. A neoprene washer between the bracket and the cell allows me to lock the cell in place, yet it can still be moved by hand.

The tube is 8 by 11 by 58 inches and made of 1/4-inch plywood. It is glued together with quarter-round molding in the corners for strength. The back plate is 1/2-inch plywood and is tilted about 2.3 degrees, the same amount as the primary. After painting the tube inside and out, the primary was installed and then measurements were made to space

Plan for the Correcting Lens Cell



This cut-off lens cell squeezes the corrector lens as close to the incoming light path as possible, and also allows offsetting the lens elements.



the corrector cell from the primary. The cell bracket was bolted on with two screws and then the holes for the diagonal and eyepiece focuser were made.

The diagonal holder is no more than a piece of PVC pipe with a 45-degree cut, glued to a block of wood. The top end of the wood block has an adjustable bolt to allow the mirror to be tilted to the correct angle.

I borrowed the mount from my 12-inch telescope because the tube length was similar. Incidentally, the mount uses my "famous" curved bolt drive with a 19-inch radius that gives it very smooth tracking for two hours. I recently replaced the synchronous motor with a small geared stepper motor with a simple drive designed by a friend of mine that runs off four D-cells.

Collimation

Set up and collimation were easier than I expected. Before the corrector cell was installed, I turned the setscrew slightly more than two revolutions after it contacted the concave lens. This gave it about 0.100 inch of decentration. I then installed the cell and made sure it was square to the tube. I tilted the corrector cell to about where I thought it should end up.

Next, the diagonal was adjusted so that it was looking at the center of the convex surface of the corrector and eyepiece barrel was in line with the reflection of the primary.

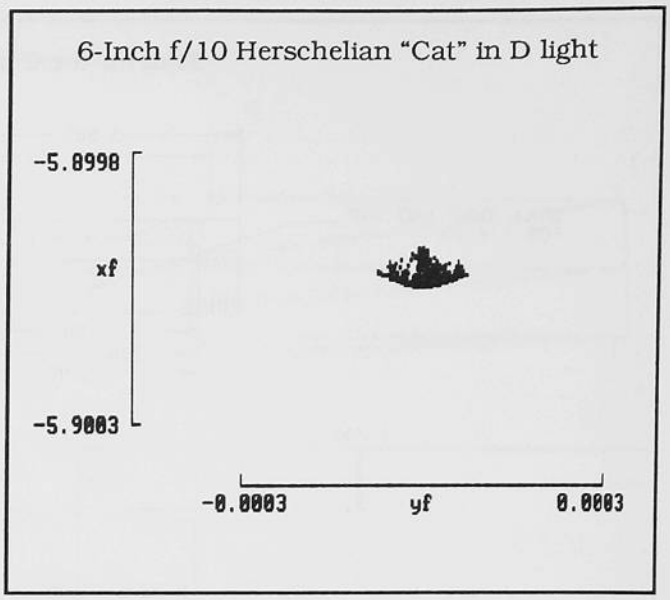
To set up the spacings correctly, I cut a piece of 1/8-inch dowel so that it would fit inside the tube just behind the corrector cell. I put a straight pin through the rod and centered the pin on the light cone

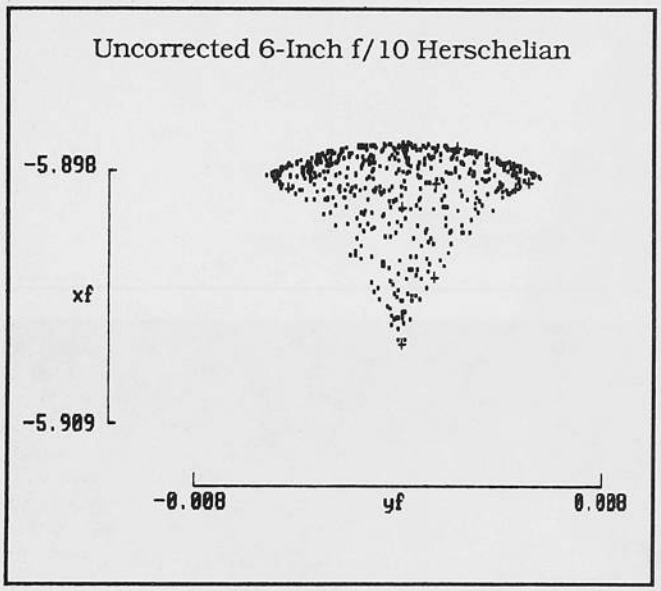
Spot Diagrams for the Herschelian

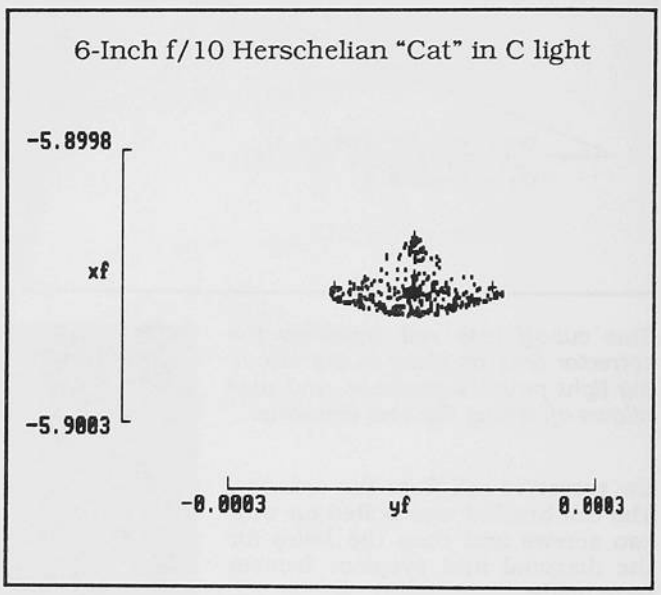
These spot diagrams allow you to compare the optical performance of two uncorrected Herschelians and show the axial performance of a catadioptric Herschelian at three standard wavelengths.

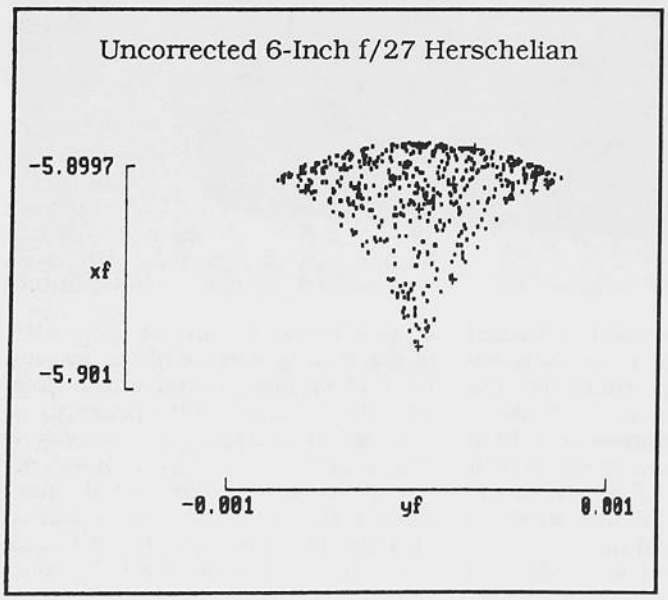
The f/10 and f/27 systems have been evaluated at the same distance off the optical axis (shown on the xf scale). Note the differing scales: the length of the x-scale is 0.011 inches in the f/10 system and 0.0013 inches in the f/27 system, or eight times smaller. The diameter of the Airy disk in the f/10 system is 0.00054 inches; for the f/27 system, it is 0.00146. The f/27 system thus would give farily good images but the uncorrected f/10 system would not.

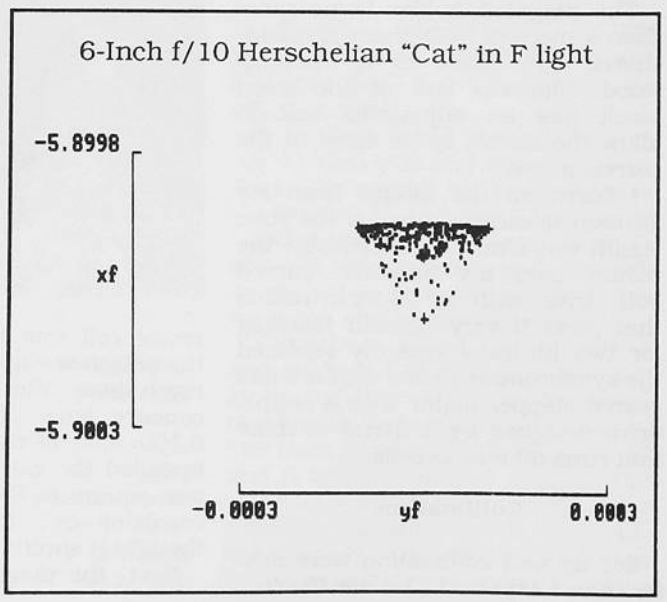
In the light of D, C, and F (yellow, red, and blue, respectively), the spot is much smaller the Airy disk and the images will therefore be limited by diffraction.











coming out of the corrector. Using Beam 3, I computed that the distance from the optical axis of the incoming light to the axis where it enters the corrector lens (marked with a pin on the dowel rod) should be 4.48 inches. I inserted another pin 4.48 inches above the first pin in the dowel and put it in the telescope tube perpendicular and square to the tube as before, then adjusted the primary so that the dowel rod and both pins were centered on the telescope axis.

The dowel was then removed, and while focusing on a star, I reached inside the tube and tilted the corrector cell to make final collimation adjustments. After some experience aligning this telescope, I've found that after rough alignment with the alignment pin-stick, the mirrors never have needed to be adjusted again. Only the corrector needs final adjustment.

Final adjustment is done on a star at high power in and out of focus. The only aberration seems to be astigmatism, which shows up an oval shaped star that rotates 90 degrees going through focus. If the long axis of the oval shaped star is either perpendicular or parallel to the telescope tube (optical axis), then the corrector only needs to be tilted to eliminate the astigmatism.

If the long axis of the oval in at some other angle, however, then the corrector must be both rotated and tilted to remove the astigmatism. I added a slot in the bracket that holds the corrector cell so that it can be rotated slightly. Your goal in collimation is to get perfectly round star images inside and outside of focus. Once you realize which adjustment to make the rest is easy.

Optical Specifications
Catadioptric Herschelian Telescope

Primary		
Diameter	6.0	12.0
Radius (R1)	-120.0	-245.423
Tilt	2.88°	2.277°
Corrector 1		
Radius (R2)	-6.482	-7.815
Glass	BK7	BK7
C.T.	0.365	0.491
Diameter	2.900	2.960
Radius (R3)	-6.755	-8.173
Decentration	0.108	0.104
Corrector 2		
Radius (R4)	6.755	8.173
Radius (R5)	6.755	8.173
Glass	BK7	BK7
C.T.	0.623	0.700
Diameter	2.764	3.00
Tilt at R5	-16.02°	-14.090°
X position R5	-4.594	-7.956
Z position R5	14.628	23.1728
Focal position		
X	-6.028	-9.75
Z	0.0	0.0

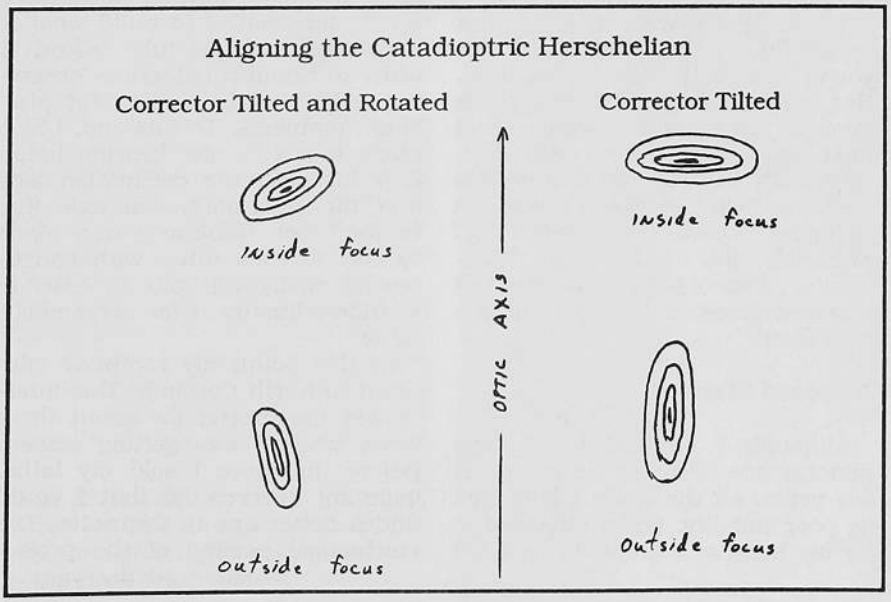
Performance

I was pleased with the system's performance. It turned out better than I thought. The star diffraction disks are picture-perfect and really make me think about making a larger scope. No trace of color is detectable. Beam 3 says that 1/2-degree off-axis the field should have 0.004 inches of coma -- not as good as a Newtonian and with a small field tilt. With my lowest power, a 32mm Brandon Plossl, I think I can just detect the field tilt, but I haven't bothered to compensate for it either by tilting the eyepiece holder or the eyepiece. At any rate, the field tilt gets lost in the eyepiece aberrations at the edge of the field and overall the field is still quite good.

One of the things I want to work on is how to make the corrector as one piece of glass (method #2). I have a laser, and maybe I can work up a way to measure the wedge using it and some calculations on Beam 3. It would be an advantage to have a one-piece lens because a cemented lens can't be coated.

I have to admit I got a lot of satisfaction from designing this scope on the computer and then seeing pieces of glass, wood, and metal come together to function as a telescope.

Ed Jones
610 Woodland Drive
Cincinnati, OH 45244



Titanium-Tubed and Computer-Controlled

Those who are skilled in star-hopping probably consider computer-controlled telescopes the epitome of laziness. But no lazy person would ever build a computer-controlled telescope. When you build one yourself—out of frustration, perhaps, because you can't seem to learn how to star-hop—you discover that all the hard work goes in right up front. The "lazy" part comes only after years of effort. The story of my 10-inch computer-controlled Newtonian is a testament to this fact.

The First Version

I constructed the first version of my computer-controlled telescope in 1976. It had a horseshoe mount that, as a first attempt at telescope making, left a lot to be desired. I learned from building it that long, thin-wall aluminum channels attached to a horseshoe result in an instrument best described as a seismograph.

The tube assembly, however, was a different matter. The open-trussed tube was scroungineered from surplus jet aircraft engine components sometimes called burner cans, which I found at an aircraft salvage yard in Miami. I have been told that if these parts had not failed magnafluxing tests and had remained in service, they would have been worth about $6000 each. As it was, I only paid $6 dollars per section.

The 10-inch f/5.6 Coulter primary mirror, with an excellent figure, is mounted in a nine-point flotation cell. A three-vane spider assembly holds the diagonal; I prefer the resulting six thin diffraction spikes over the four heavy spikes (really four pairs) that four vanes produce.

The finder was made from the only remaining objective of a pair of damaged 7x50 German binoculars found at a pawn shop and an eyepiece from a microscope. I have tried many different things for cross hairs, from hairs snatched from my sleeping (or so I thought) daughter's head to spider webs (the hardest part is finding the spider again after you've placed the first cross hair). But baby-fine hair isn't nearly fine enough, and spider webs collect dust and become brittle with time. Eventually I discovered that certain grey multi-strand wires contain a stripping cord composed of extremely fine but durable filaments. Two LEDs, mounted at ninety degrees, are used to illuminate them.

A Second Start

Although I enjoyed the optical performance of my scope for about five years, all the while I lamented its poor stability. When I decided to try my hand at astrophotography, I quickly realized that a solid mount was a necessity. Small computers were just coming on the scene, so I thought that it would be ideal if I could use one to control the scope to find and photograph objects I might not even be able to see.

But first, I had to embark on a painfully slow journey to acquire the mechanical components for a new, rigid mount. I decided that I first had to have a lathe with which to make parts and located an ancient belt-driven one which could turn fourteen inches and had a six-foot bed. With this machine I made two tap-cut worm gears, each of approximately twelve inches diameter. I had decided to build what is known as a torque tube mount in order to retain a ladderless observing height while eliminating pier-crash problems. To this end, I also made tapered roller bearing housings for both the declination axis and the right-ascension axis (the torque tube). These axes were made to bolt to each other with flanges having push/pull bolts in order to provide adjustment for perpendicularity.

At this point, my company relocated to North Carolina. This interrupted the project for about three years while I was getting settled. Before the move I sold my lathe, believing (incorrectly) that I could find a better one in Charlotte. The mechanical portion of the project

languished until I changed employment to a company with a well-equipped machine shop and—most fortunately—few concerns about employees using equipment after hours.

I Meet the Stepper Motor

In the meantime, I decided to learn whether or not I could make a comput drive stepping motors. This was no small task. Not only did I not have a computer, but I didn't have the slightest idea how they worked. Even BASIC wasn't basic to me.

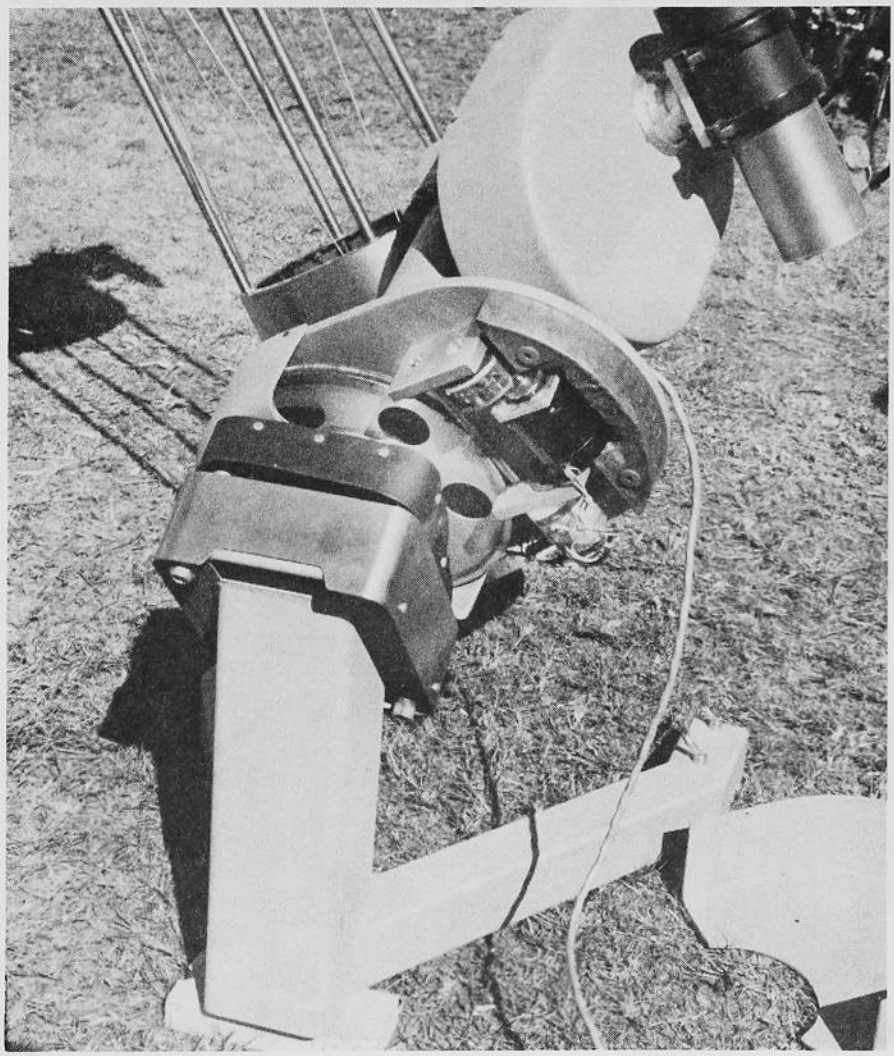
I purchased a Radio Shack Color Computer (CoCo) of 64K memory, ostensibly my children's Christmas present. Fortunately, they wouldn't have a thing to do with it. An entire year was spent in developing a program and designing and building an electrical interface that would drive the stepper motors.

(While a purist might turn up his nose at the thought of using the lowly CoCo for such a purpose, there are some advantages, primarily the fact that I can inexpensively replace the computer if it is damaged at a star party. I even bought a spare for thirty dollars at the swap table of our club's convention last year. Try that, Big Blue users!)

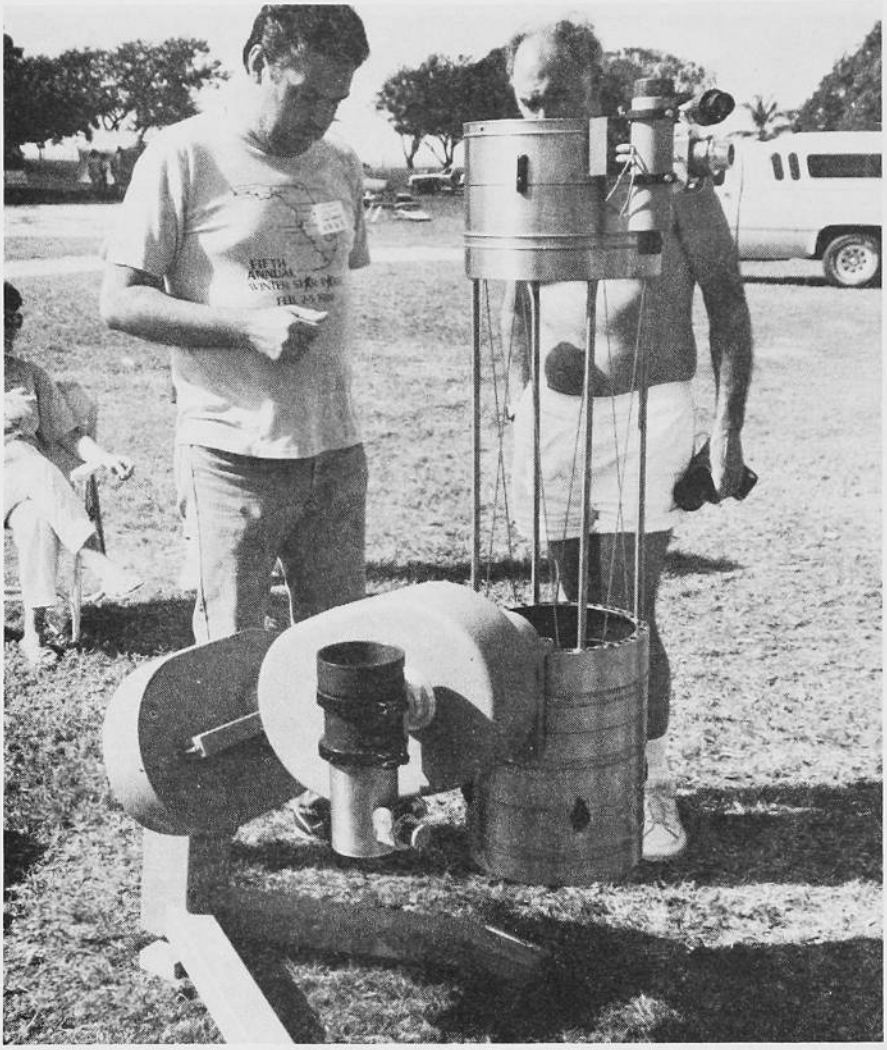
The interface unit connects to the CoCo through its game cartridge port, right on the data bus. I gutted a game cartridge for its case and added a gold-plated card-edge connector board and ribbon cable to connect the data bus to the interface unit housing a 6821 PIA (peripheral interface adapter). This device is programmed from BASIC to configure an eight-bit group of data lines as outputs, which in turn light the LED portions of eight opto-isolators.

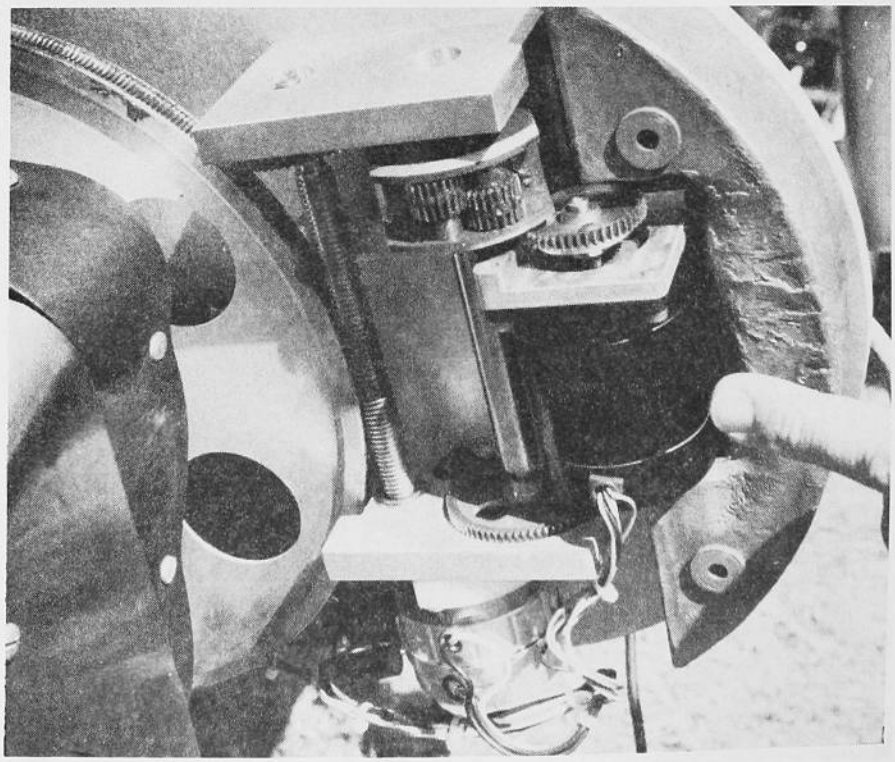
The power for the PIA and the LEDs is derived from the CoCo game port; the remaining power for the interface comes from from its own power supply. The opto-isolators provide electrical isolation between the two power systems.

The power supply generates an unregulated 12 volts (DC) for the two stepper motors, the two declination motor relays, and the clock drive inverter transformer. This raw 12 volts also provides input power



This Radio Shack Color Computer drives an 10-inch reflector to its targets through a differential gear train in the clock drive system.





Two motors move the telescope about its polar axis, a synchronous motor and the CoCo-controlled stepper. Declination uses one motor.

for the regulated 5-volt supply that powers the integrated circuitry.

For slow-motion right ascension control, a crystal-controlled oscillator drive corrector is employed, similar to one first described in the August 1975 *S&T* by John B. West and Robert S. Bradford, Jr. They used discrete components to construct a 2 MHz oscillator; I used a monolithic 20 MHz crystal oscillator and added a 74LS90 decade counter to perform the required additional divide-by-ten operation.

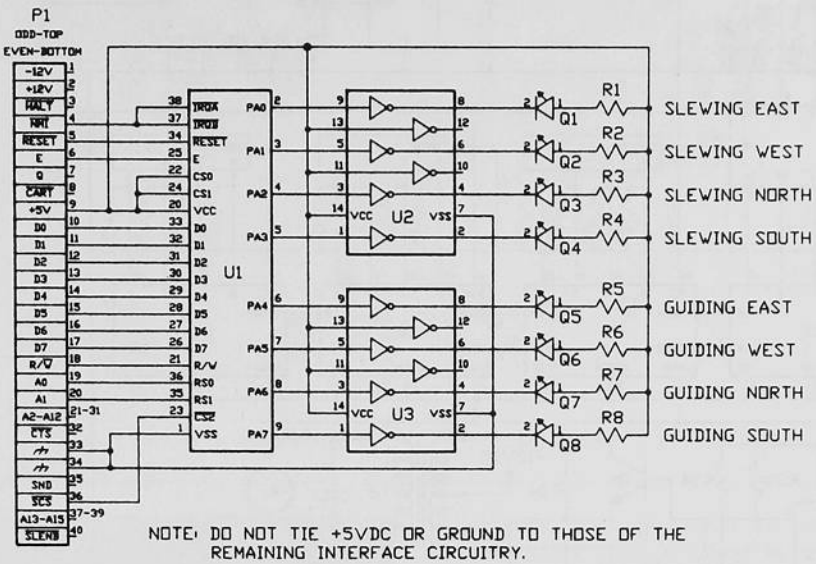
In addition, I replaced the fast and slow push-button switches with the aforementioned opto-isolators that drive schmitt trigger inverters and allow use of the computer's joystick for guiding. Slow-motion declination control is performed by using two of the opto-isolators to energize either of two miniature relays to power the declination guiding motor. The relays and the motor are 12-volt units.

For slewing in right ascension and declination, two identical circuits were constructed to convert pulse trains generated by the computer into the required four-wire sequence for stepping the two motors in half-step mode. The selection of axis and direction of rotation is determined by which data line is being pulsed (via the four remaining opto-isolators), and the distance slewed is controlled by the number of pulses sent.

The CoCo Software

The computer program is loaded in via a tape recorder. Once again, the purist might question why I haven't used a disk drive. The answer lies in the fact that on the CoCo the disk controller plugs into the game cartridge port already dedicated to the telescope interface connector. A Y cable could be used to connect both devices, but the time required to load the program from tape is not excessive. Furthermore, because I use a trailer to carry both the scope and the computer control system, a disk drive would be more subject to damage in transit.

The program currently consists of two parts: an initialization program and the main working program. Both are reproduced herein,



NOTE: DO NOT TIE +5VDC OR GROUND TO THOSE OF THE REMAINING INTERFACE CIRCUITRY.

FIG. 1 - ELECTRICALLY ISOLATED SECTION

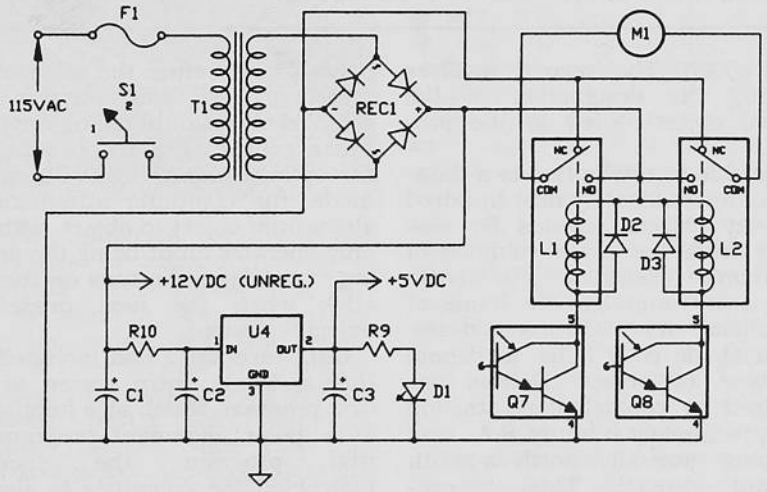


FIG. 2 - POWER SUPPLY & DECLINATION GUIDING

Parts List
Interface Unit

C1	Capacitor, Electrolytic, 20K uF, 20VDC
C2	Capacitor, Electrolytic, 1 uF, 35VDC
C3	Capacitor, Ceramic Dipped, .33 uF, 50VDC
C4-C6	Capacitor, Ceramic Dipped, .01 uF, 50VDC
C7	Capacitor, Polyester Film, 1 uF, 600V
D1	LED, Power Indicator (*)
D2-D13	Diode, 1N4002
F1	Fuse, 1-1/2 Amp
L1,L2	Relay, Cornell Dubilier #603-12V
M1	Gearmotor, 12VDC (*)
M2	Gearmotor, Synchronous (*)
M3,M4	Motor, Stepper, 12VDC, Oriental Vexta #PH268-22
OSC1	Oscillator, 20 MHZ, Vectron #C0238
P1	Connector, Game Port (Ref.)
Q1-Q8	Opto-Isolator, #4N30
Q9-Q18	Transistor, Power, 2N3055
R1-R9	Resistor, 1K, 1/8 Watt
R10	Resistor, 6 Ohm, 25 Watt
R11-R26	Resistor, 470 Ohm, 1/8 Watt
R27-R32	Resistor, 100 Ohm, 1/8 Watt
R33-R42	Resistor, 270 Ohm, 1/4 Watt
REC1	Bridge Rectifier, General Electric #KBPC25-02
S1	Power Switch (*)
S2-S5	Switch, BCD Thumbwheel (*)
T1	Transformer, Stancor #P-8660
T2	Transformer, Signal #241-6-20
U1	PIA, #MC6821
U2,U3	Hex Inverter, Open Collector, #7405
U4	Voltage Regulator, #LM323
U5	Decade Counter, #74LS90
U6	Data Selector, #74LS157
U7-U11	Up/Down Counter, #74LS192
U12	J-K Flip/Flop, #74LS73
U13-U17	Dual Peripheral Driver, #75451
U18	Hex Schmitt Trigger Inverter, #7414
U19	Quad 2-Input Positive-Nand Gate, #7400
U20,U21	Up/Down Counter, #74LS193
U22,U23	BCD-to-Decimal Decoder, #74LS42
U24,U25	Quad 2-Input Positive-And Gate, #74LS08

(*) = User's Option

although I have omitted the bulk of the data in the observing program for the sake of brevity. Apologies are made for the absence of remarks, but this was done intentionally in order to leave as much room as possible for data. Because they are lengthy, and there is a danger of transcription errors, I will provide a CoCo-readable tape of the programs to any *Telescope Making* reader for a nominal charge, should you desire to build a similar system.

The initialization program POKEs three machine-language subroutines into memory. The first is a public domain routine to reconfigure the memory map of the CoCo to allow use of the otherwise unusable upper 32K of memory. The other two subroutines generate pulse trains for slewing under automatic computer control or by joystick control, respectively.

The automatic slewing subroutine uses decrementing loops to provide ramping up and ramping down of the stepper motors for softer starts and stops. The joystick slewing subroutine has only ramp-up capability

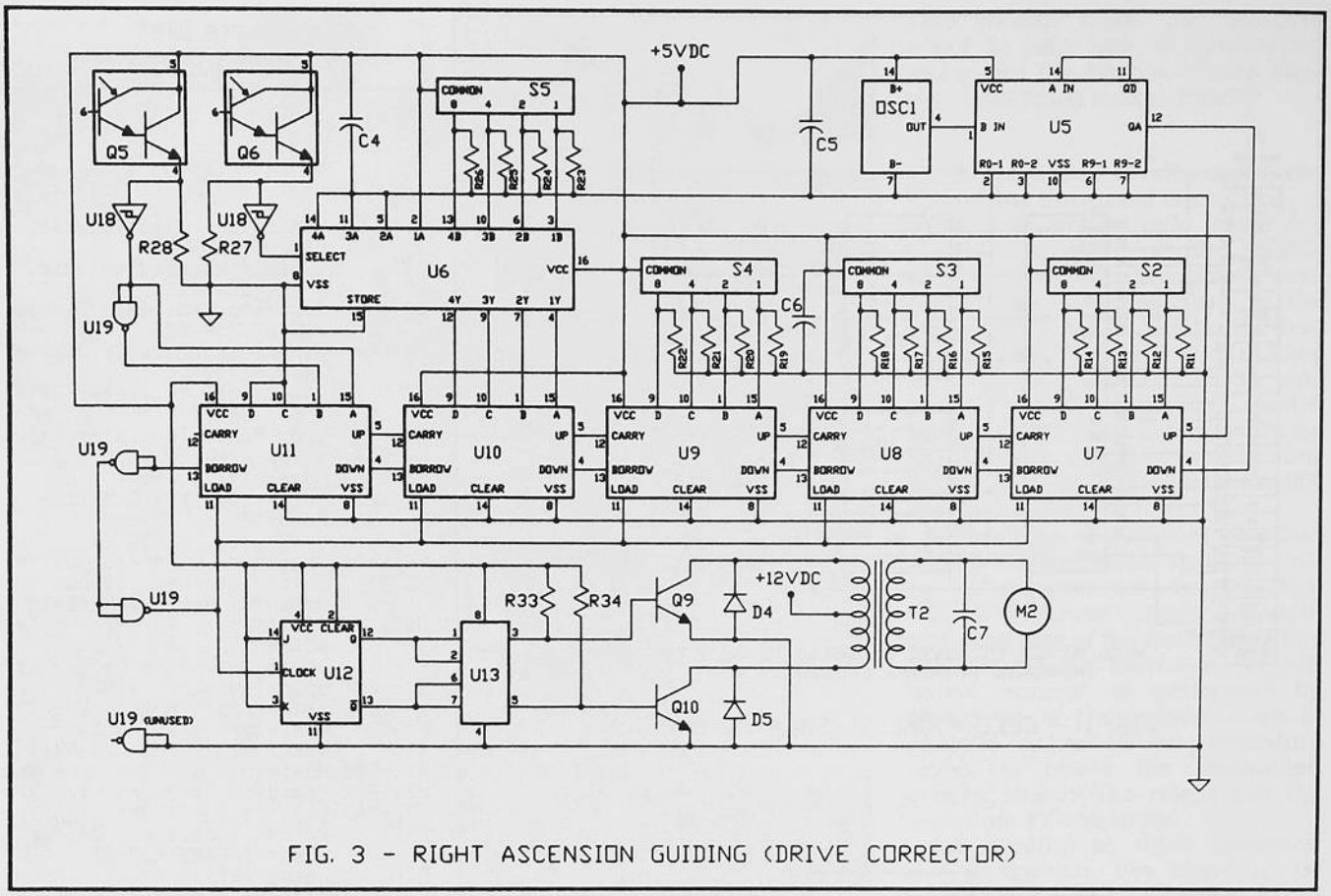


FIG. 3 - RIGHT ASCENSION GUIDING (DRIVE CORRECTOR)

because the computer cannot anticipate when the operator is going to stop slewing. Overshoot, if it exists, is not detectable.

Both slewing subroutines contain delay loops to control the top speed of the stepper motors. The value for the number of iterations is POKEd in at the beginning of the second program and can be adjusted, if necessary, to increase motor torque under low temperature or voltage conditions.

The second program is the main telescope operating program. On running the second program, the operator is prompted to enter the current date, which will be used to perform precession conversions later. Following this entry, a screen with the names of sixteen bright stars is presented. The operator selects one of these as a starting point and is then prompted to align the scope on that star, either manually by overcoming axis slip clutches or by slewing to the star under joystick control.

Once the telescope has been aligned, the operator is presented a screen showing four options for locating objects. The first allows the observer to enter right ascension and declination coordinates and their epoch. The second involves entering the designation of the desired object stored in the program.

Available in this option is a database of approximately nine hundred deep-sky objects selected for seeability from the three volumes of *Burnham's Celestial Handbook*. Each entry contains the name of the object, its 1950 coordinates, and a single code letter to denote the type of object. Entries are arranged by constellation, starting at approximately 0 hours R.A., and sweeping generally north-to-south or south-to-north. This arrangement is beneficial in keeping the scope working on the meridian during the course of an evening. In order to use as little memory as possible, objects below the horizon from my latitude were not included in the database.

The third and fourth options are semi-automatic or fully automatic slewing modes in which the computer selects the object to be viewed. A screen is presented that allows the operator to select all objects on the list, Messier objects only, or specific types of objects such as globulars, or galaxies.

In the semi-automatic mode, the operator can refuse the selection by resetting and can observe the selected object until telling the computer, via the keyboard, to return to the options menu. In the automatic mode, the computer automatically slews from object to object, with the only operator input being the pressing of both pushbuttons on the joystick when the next predefined object is desired.

Until recently, I had included the time-and-date entry screen in the first program, which also functioned as a polar alignment program. In that program, the operator instructed the computer to slew to another predetermined star. After slewing to each new star, the observer had to make appropriate altazimuth adjustments to polar-align the telescope, and then was given the choice of returning to the initial star, slewing to the next bright setup star on the list, or exiting the polar alignment program and loading the main program. Before exiting, though, the computer dissected and stored the date and the current position into an upper area of memory, where they were retrieved and reassembled by the observing program.

I abandoned this two-star polar

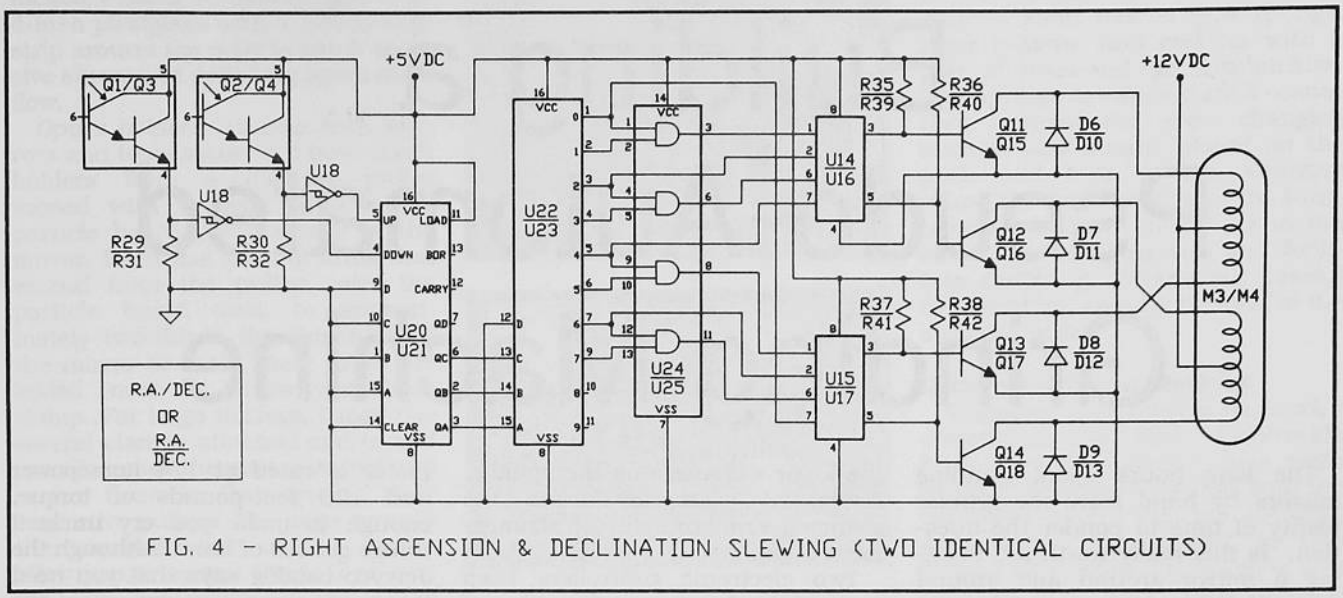
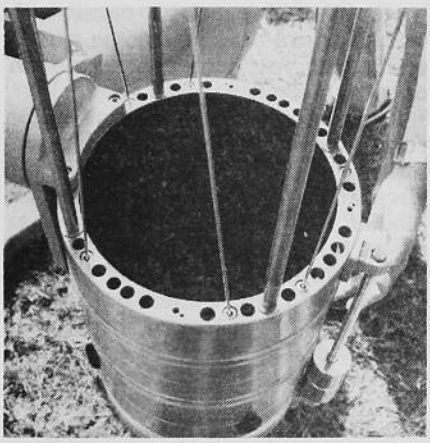


FIG. 4 - RIGHT ASCENSION & DECLINATION SLEWING (TWO IDENTICAL CIRCUITS)



alignment program because I was never able to learn the rules of thumb for which adjustment, altitude or azimuth, was required to bring the scope into polar alignment. I have discovered that the tried and true drift method of polar alignment brings about superior alignment in less time than the point-and-tweak method. Besides, the latest program takes much less time to load.

The Finished Mount

Having finally gotten motors turning, my attentions returned to the mount. At a local surplus house I found a pair of high-quality military differentials, of unknown original use. These devices are used to sum the motions of the stepper motors with either the clock-drive motor or the declination guiding motor. This approach allows for a much simplified drive system over that of a system where the stepper motor must also serve as a clock-drive motor.

Software is simpler, too, because the computer does not have to keep track of sidereal time, but only the relative hour angles of various objects. The stepper motors remain on and locked when the telescope is not slewing in order to prevent freewheeling through the differential under power from the guiding motors. And, because the steppers are only used for slewing, there is no concern about pulsations ruining photographs.

The torque-tube mount is balanced with two lead weights concealed in the gear housings. One weight is attached to the declination axle and is pie-shaped to compensate for an imbalance of the optics tube. The gear housing covers were made of fiber-glass, shaped in a female wooden mold, and took about twenty hours to fabricate (and about twelve more hours to rebuild when the first cover stuck tight, requiring fracturing the mold).

The altazimuth adjustments for the mount are somewhat unusual, consisting of three heim fittings (two of which are adjustable) that suspend the non-rotating polar axis shaft over the leg-and-pier assembly. While this arrangement has worked fine, I intend to replace it with of adjustments that will allow for motions similar to altazimuth, but rotated forty-five degrees (so that east, when using the drift method, is forty-five degrees up from the eastern horizon, and the meridian, for the method, is forty-five degrees west of the true meridian). This modification enhances the drift method because the eastern stars are neither buried in horizon clutter nor displaced by refraction.

For photography I built a 2-inch focuser with an integral off-axis guider. The entire unit swivels on a Delrin collar to enhance acquisition of suitable guide stars. To the same end, a surplus optical bench assembly containing an adjustable mirror is used to scan the off-axis prism. This assembly carries the guiding eyepiece and also swivels for viewing comfort. The guiding eyepiece is a home-built microscope, which provides high magcnification with comfortable eye relief. The design of the off-axis guider/focuser was aided by use of a CAD system at work to perform the ray tracing.

The system has performed very well, at least whenever I take the time to do an adequate polar alignment. One benefit of a computer-controlled system is that once you have it locating objects nicely at moderately high powers, then during photography drift is almost nonexistent. Of course, right ascension gearing errors still exist—as they always do—and require monitoring.

One negative to a computer-controlled system, at least one that is portable, is that set-up time can seem interminable, especially when the Dobs have been pulling in objects for an hour while you were getting polar aligned (and, of course, their owners delight in calling your attention to that fact!). Later on in the evening, though, they will invariably ask you to show them something they can't find. Aahh, sweet revenge!

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Building a Pseudo-Automated Grinding Machine

The long hours spent grinding mirrors by hand leave the grinder plenty of time to ponder the question, "Is this really worth it?" Pushing a mirror around and around gets old fast, and the quest for that elusive paraboloid soon seems to be an exercise in futility.

When I decided to get around to that twelve-and-a-half incher, I knew that a machine loomed large. But not any machine. I wanted a machine that would be economical and would not saddle me with a protracted workout on the lathe or milling machine. I found the solution in an article by Brian Knight called "A Semi-Automatic Grinding and Polishing Machine" in the book *Advanced Telescope Making Techniques*, **Volume 2**. (I heartily recommend this book.)

My machine is an evolved version of Brian's machine and should be called something like "A Pseudo-Automatic Grinding and Polishing Machine with Electronic Controls." In addition to automating the swinging arm, I've added a timer for keeping track of wets in grinding and an automatic polishing- agent dispenser for polishing. The system works quite well—during a polishing session it can run essentially unattended for several hours at a stretch.

The grinding machine is built on a horizontal table, with the mirror and tool roughly at its center, in a splash pan mounted atop a wooden box roughly a foot high. The box contains a gearmotor that drives a vertical spindle that turns the lower workpiece, either the tool or mirror, as the case might be.

The upper workpiece is controlled by two arms. The overhead arm and counterweight reduce the weight of the upper workpiece, and the swinging arm drives the upper workpiece from side to side across the lower workpiece on the spindle. A second gearmotor drives the swinging arm through an arrangement of pulleys.

Two electronic controllers keep track of the duration and number of wets in grinding and the regular application of polishing agent. I have found this degree of "pseudo-automation" relieves much of the tedium of optical work.

The Mechanical Parts

Turntable motor. I opted to make the turntable motor a direct-drive gearmotor rather than a motor with pulleys and a brake. I mounted the motor beneath a metal plate, obtainable in the remnant section of a steel yard. It is supported, shaft upright, on a wooden box with 2.5-inch holes on all four sides. On the bottom I placed an auxiliary cooling fan (Jerryco variety for about $3.50). This fan is turned on independently of the gearmotor to allow cooling between wets. The base is a piece of discarded countertop with reinforcing 2x4s, although if I did it again I would use a minimum of 3/4-inch plywood because the particle-board countertop has too much flexure. This flexure is evident on large diameter mirrors from the torque generated from the turntable through the swinging arm towards its mounting post.

Although a new gearmotor would be expensive, the Jerryco Company sells a surplus 100-rpm Bodine gearmotor for less than $30—well within my budget. It is a well-built motor with ball and needle bearings. It has ample torque for my machine—I have yet to stall it even with a 12-inch mirror—but it will arrive somewhat dirty from Jerryco. I cleaned mine with solvent.

The motor is listed as continuous duty, and it incorporates a fan to cool its aluminum-finned body. The motor is rated at 1/4 horsepower and 125 foot-pounds of torque, enough to make you cry uncle if things get out of hand. Although the Jerryco catalog says that you need to supply your own capacitor, the motor that I received came with one. If yours does not come with a capacitor, you can readily obtain one at an electric motor shop.

It is important to keep this motor cool. However you mount the motor, make certain to allow sufficient air circulation, or even insert a small biscuit or computer cooling fan to assist in cooling the motor. I would also recommend attaching a thermal fuse to the ribbed housing of the motor to protect against burning out of the motor's windings. (I used a 121° C thermal fuse.) I never run my motor for more than a two and a half hours without a good cooling off period.

It's a good idea to wire both the turntable motor and the motor that powers the swinging arm to the thermal fuse so that both motors will shut down if you're working the motor too hard. Do not use a thermostatic shut-off device, because it will switch on the motors when it is cooled and an unexpected start up could well prove disastrous.

Splash pan. For mirrors under 8 inches in diameter, I use a home-built splash pan between the gearmotor and turntable. This catches excess grinding slurry, polishing compound, and water the machine throws off. It is simply an oil drain pan with a hole in the center. A piece of sprinkler pipe about 1/2 inch long is siliconed to the center to provide protection for the motor's shaft and seal. The pan also has a 1/2-inch hole on its circumference to allow a long-handled Allen wrench to reach the setscrew in the pulley that I use as the turntable.

For mirrors and lenses over 8

inches, I use a 30-inch square of 1/4-inch plexiglass with a 1-inch-high strip around the edge to catch abrasive slurry and polishing agent overflow.

Optics holders. To grip both mirrors and tools securely, I have made holders from a die-cast pulley topped with a circle of 5/8-inch particle board the diameter of the mirror. Each has a set of arms that extend from the pulley, over the particle board disk, to approximately two-thirds the thickness of the mirror or tool. These arms are folded over a screw-type hose clamp. For large mirrors, I may use several clamps attached end to end to encompass the mirror or tool and secure them to the arms of their respective pulleys. The arms around the circumference of the pulley allow you to secure the tool or mirror to the pulley without the fear of it falling out, especially if it is heavy.

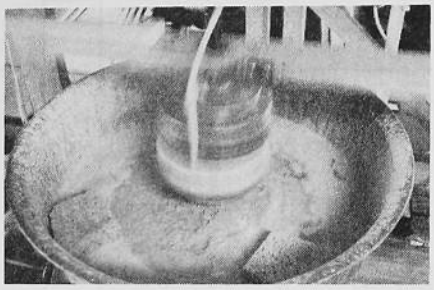
Strain is relieved by the use of rubber bathtub anti-slip tape. I usually paint a coat of contact cement on the outer circumference of the mirror and tool and place a strip of the rubber tape around it—but avoid tapes coated with abrasive compounds!

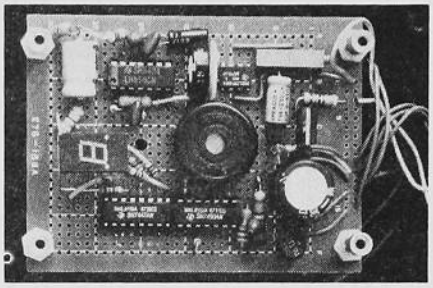
I use the old "wrap it with duct tape" method to secure mirrors smaller than eight inches. Note that although duct tape is water resistant, it is NOT waterproof. Be careful when using duct tape for load-bearing. I wrap the tape right over the arms. A good coat of paint on the arms help to keep the rust down because the arms do tend to get sanded quite a bit by the action of the grinding compounds.

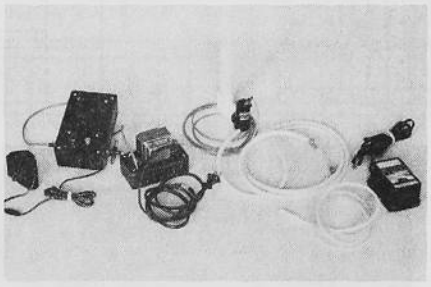
Overhead arm. To counterbalance heavy mirrors and tools, I use the overhead arm. I have not had as much luck using it for figuring as Knight did in his article, but it is good for lessening the weight. I have even used the arm to lift a stuck lap from a 12.5-inch mirror by suspending the lap/mirror combination in 150^o hot water. The overhead arm also holds the supply hose that comes from the automatic polishing dispenser.

Swinging arm. This arm moves the upper workpiece over the rotating lower workpiece. A framework at one end of the machine supports the moving end; a fixed upright 30 inches away secures the other end. This post must be solid; I reinforced mine with guy wires to the edges of the table.

Swinging arm motor. The swinging arm is driven by nylon cords actuated by a crank driven by another gearmotor from Jerryco. It is a smaller motor that runs at approximately 59 rpm. It normally would be too fast to move the swinging arm across the mirror, so I put it through a set of pulleys to reduce the stroke speed to a comfortable cycle of one full to and fro stroke every 3 seconds. The motor that runs the swinging arm has a switch on it to control it independently, as does the 100 rpm gearmotor.







Combining a grinding machine with an electronic timer and a pump for the polishing slurry results in a machine that almost runs itself.

The pillow block bearings are bronze motor bushings held down with strap steel pipe clamps screwed and epoxied to a couple of 2x4s. Be certain that the shaft you are using is in the bearings to allow for proper alignment. The shaft is secured to the center of a 1-inch-square steel section 8 inches long. Over the length of this piece of steel a series of holes are drilled half an inch apart to produce different stroke lengths.

Two nylon cords go out of those holes, through a swivel, through pulleys, stout torsion type springs, more pulleys, and end up with a pair of hook-and-eye turnbuckles. The springs are important because they cushion the ever- changing stresses and strains placed on the pulls and tugs of the swinging arms. The hook portion of the turnbuckles engage a screw eye in the end of the swinging arm and facilitate centering, decentering (useful in polishing), and the removal of the swinging arm.

Grinding with the Machine

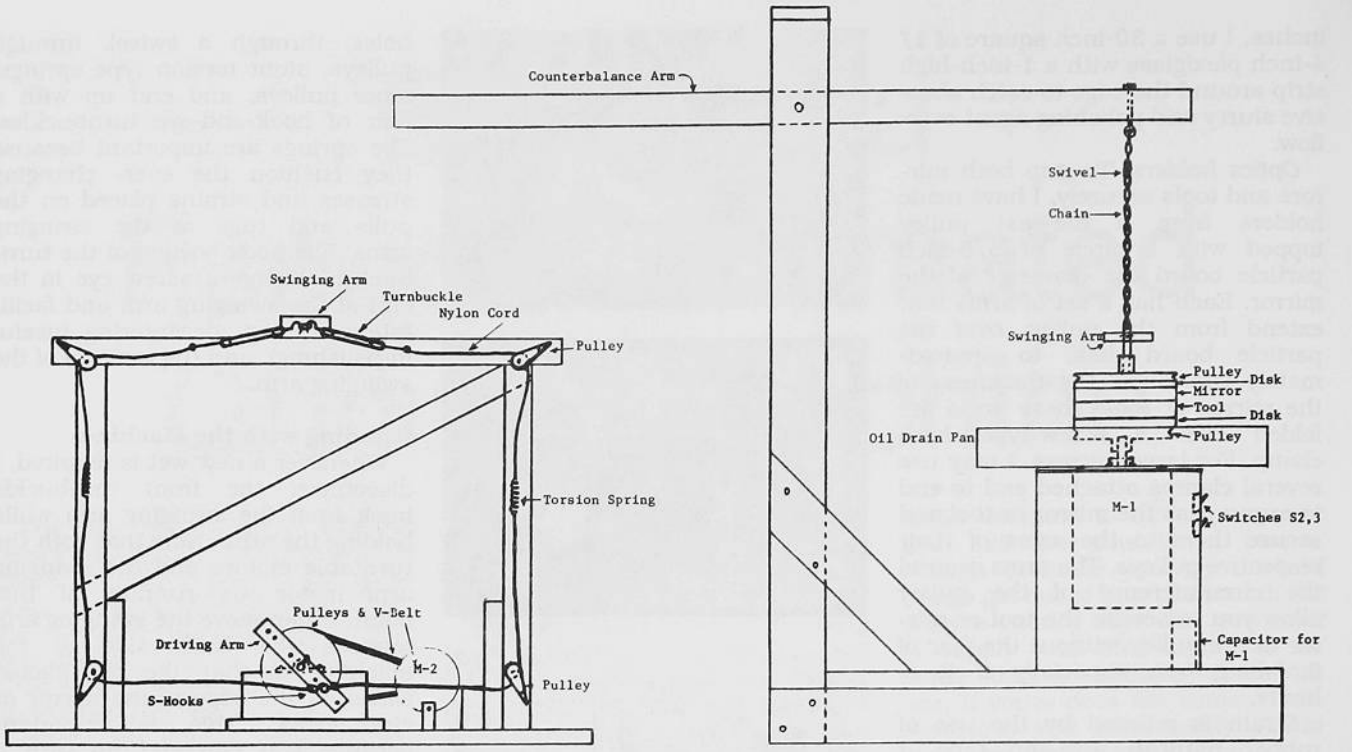
Whenever a new wet is required, I disconnect the front turnbuckle hook from the swinging arm while holding the arm. Note that both the turntable motors and the swinging arm motor are running at this point. I then move the swinging arm towards the back side of the machine so that the lap almost slides off the edge of the mirror or vice versa. This is important because you can end up with a stuck lap/mirror combination if you turn off the turntable and swinging arm with the workpieces centered.

I then turn the turntable motor off, sprinkle on whatever grit I'm using, give the surface a good spray from an atomizer spray bottle, move the mirror or tool back on to the center of turntable, turn on the turntable, and hook the turnbuckle to the swinging arm again.

This entire process takes about twenty seconds, roughly the time I set the grinding timer's warning LED to be on. I'll say more about the timer later.

I grind with the mirror on top most of the time. Using #80 grit, I grind down until the sag is about 0.012 inch under the target value. (I measure sag with a straight piece of aluminum from which I obtain a reading from the depth portion of a vernier caliper. A spherometer would be nice, but is too expensive.) I rely on a Foucualt tester with a dial indicator and "flash" polishing to really zero in on the final focal length. More on this later.

Continuing through finer and finer grits, I divide the 0.012-inch figure by two, and then by two again, as I work into the micron grit ranges. I think this helps eliminate pits from the previous grit size. If I am within one or two inches of the desired radius, I use 12 micron powder. Within less than one inch I grind with 5- micron powder down to 1/4 inch. Any less and I use the cerium oxide alone.

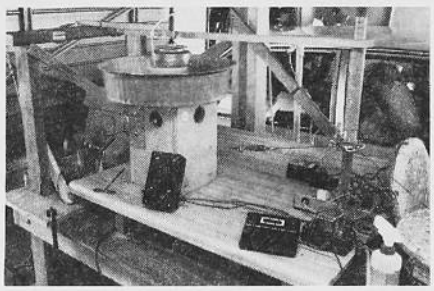


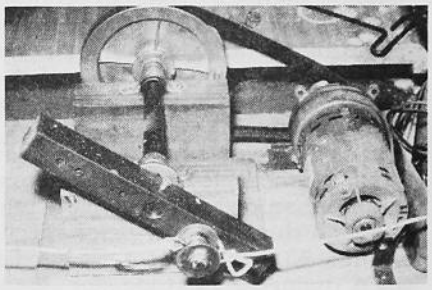
These rule-of-thumb figures are the result of my own trial-and-error experience. Sometimes switching back to the 12 micron is necessary to reach to the desired curve, because staying with the 5 micron or cerium oxide alone is slow and wastes time. I usually grind the last few wets without using the swinging arm motor at all. Instead, I rely strictly on manual random arm swings. This seems to help smooth over any zonal grinding errors.

The Electronic Timer

Anyone who has done any mirror or lens grinding knows that controlling the duration of grinding periods and the numbers of wets is essential. If the grinding periods are too short, you waste grinding powders and slow the grinding process; if the periods are too long, the grit breaks down and the work chatters or seizes with disastrous consequences.

My timer not only helps with maintaining an even grinding schedule, but it provides a visual warning and an audible tone when I should recharge the optics with fresh abrasive and also drives a counting circuit to keep track of the number of wets used. I use the counter to establish the number of wets that I use, to assure the removal of previous grit pits, and as a gauge to figure the number of wets needed to change the radius a given amount.





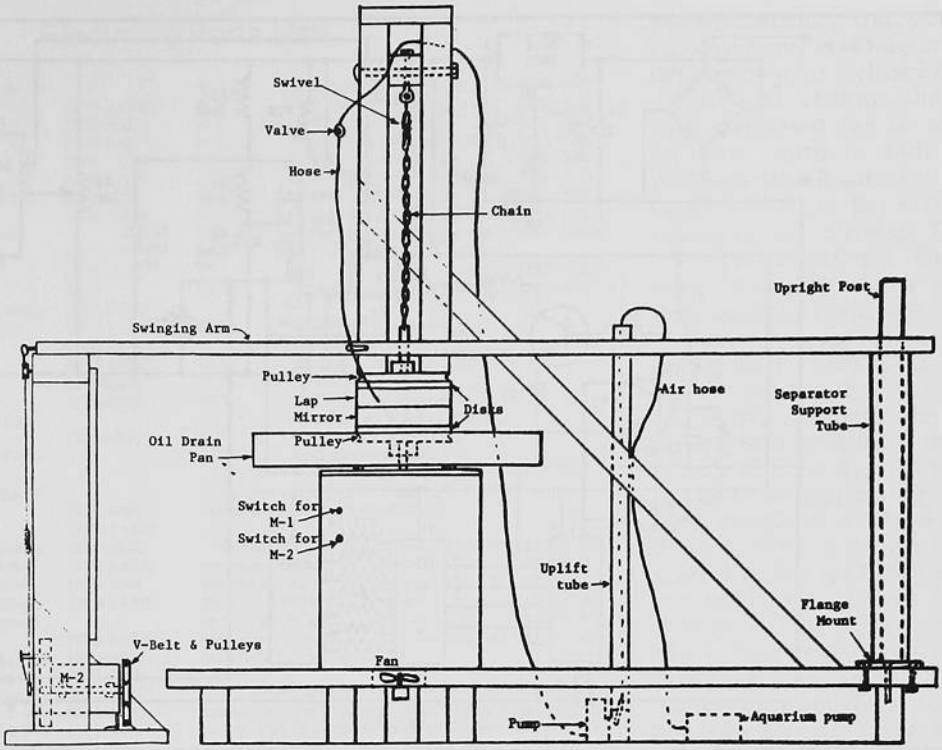
The timer also supplies a pulse to trigger a pump that squirts a dilute mixture of cerium oxide in water on the work every few minutes during polishing. The external circuit supplies the voltage and current necessary to pulse a Ford Motorcraft windshield washer pump that supplies the cerium oxide mix to the mirror every few minutes. More on that later.

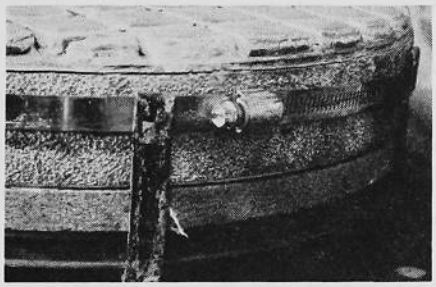
After the initial extra-long cycle, the timer can be set from one and a half minutes to a little under four minutes. You can customize the circuit to your own preference by increasing the value of resistor R3 to lengthen the time interval, or *vice-versa*. I prefer 3 minutes and 15 seconds per grinding cycle, but this depends on the temperature and humidity of your work area. My garage is often a "cool 94^o," which explains why I built the automatic cerium-oxide dispenser. At that temperature, a wet dries in four or five minutes. I set the timer slightly less than this as a safety margin.

The timer is built around the famous 556 timer chip. Different sections of the chip control the length of the audible tone and the pulse to the washer pump. This time, set to approximately 3 seconds on the prototype, can be altered by changing the value of R5 or R9.

Variable resistor R1 is set as a voltage divider that allows the 741 operational amplifier to act as a voltage comparator that lights LED-2 at the time selected to prepare for a new wet. Mine turns on approximately twenty seconds before the audible tone, which allows me just enough time to turn the turntable off, separate the mirror and tool, and apply a fresh charge of grit. I then turn the turntable back on and continue until the next interval.

The timer also supplies a pulse to the 7490 counter that controls the 7447 display driver integrated circuit that allows the common anode display to count in sequence from





zero to nine, reset, and then resume the count again.

The circuitry Q2, R6, R11, C8, and R19 allow the 7490 to reset and hold the number zero displayed on initial turn-on. If these are not used, you may get any other number due to transients, line noise, or voltage spikes.

Components Q1, R3, R7, and LED-1 allow for a circuit/counter reset via pressing switch S1. The timing voltage charged on C3 is discharged through LED-1 when the momentary SPDT switch S1 is pressed; however, it is only allowed to drop to the level normally used by LED-1, which also happens to be the same voltage remaining in C3 following the normal timing discharge that is used by the 556 timer. This keeps the 556 from going through a "dead start" warm-up, which is somewhat longer on initial turn on by maintaining a residual timing charge on C3.

All components with the exception of the polishing motor circuit are mounted on the predrilled circuit board (Radio-Shack #276-168) using standard point to point wiring. Keep the components spaced closely together because there is not much room, so little in fact that I had to sort to soldering the 1/4-watt resistors R12 through R18 direct to the pins of the display's socket. The socket that holds the common anode display LED-3 is a 14-pin wire wrap socket that is soldered to the board to allow the LED to be mounted up and away from the board and close to the faceplate of the experimenter's box.

I used 1-inch spacers between the board and the faceplate, which allowed for a thin strip of red celluloid to be placed between the faceplate and the LED for decorative purposes. A 3/8-inch-diameter hole was drilled over the location of the piezo buzzer to allow me to hear the beep, which signals the end of a wet and an increase in the display's count.

The circuit is powered by a selectable voltage battery eliminator transformer (P-1), which is used on many cassette decks and battery-operated radios. I did not put an on/off switch on the timer and the polisher circuitry because I turn the room outlets on and off with a wall switch to kill everything that may have been inadvertently left on.

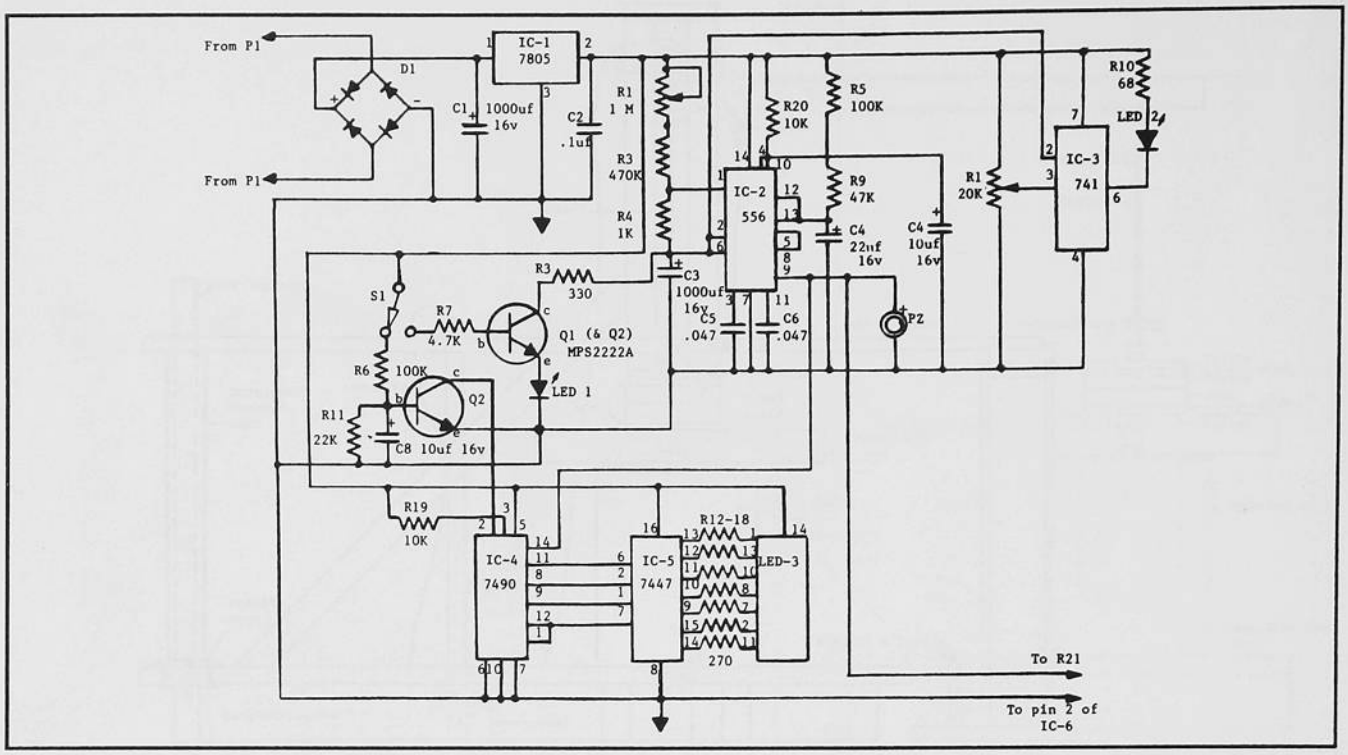
I mounted a jack that matches the output plug of the transformer. I have found that the 7805 regulator will still supply a healthy 5 volts, even with the transformer set at 6 volts. I also put a jack on the output of the 556 timer (pin 9) that drives the optocoupler inside the power supply box for the washer motor. Components are available at most Radio Shack stores. Their part numbers are listed in the parts list.

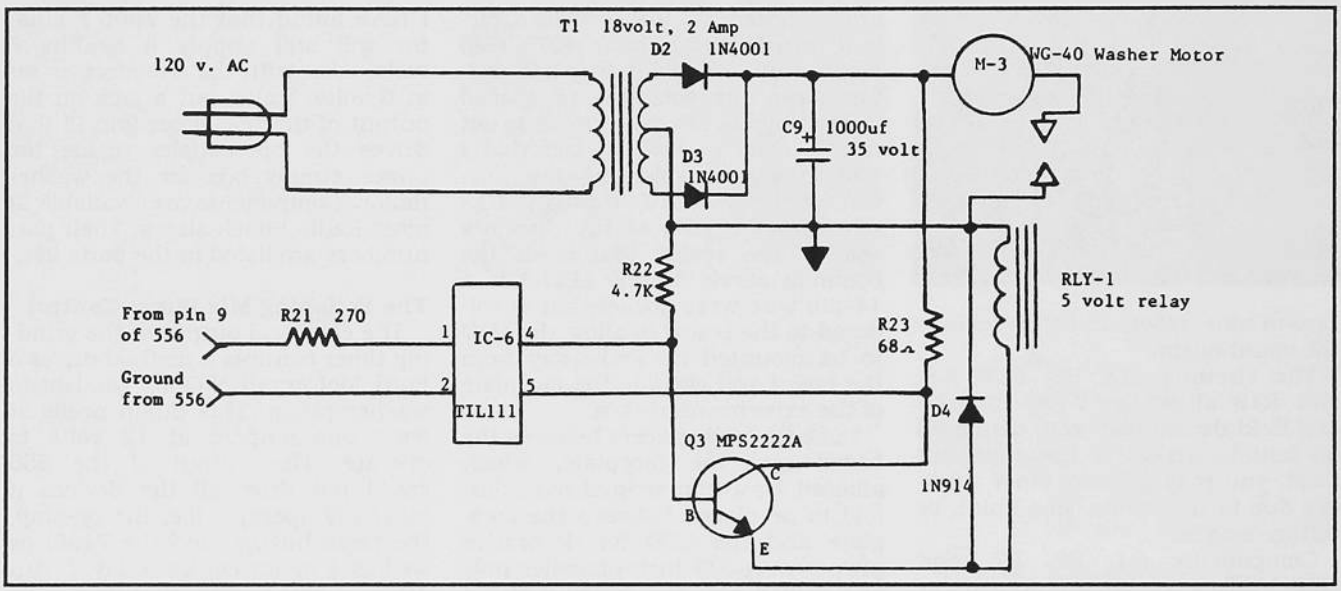
The Polishing Mix Pump Control

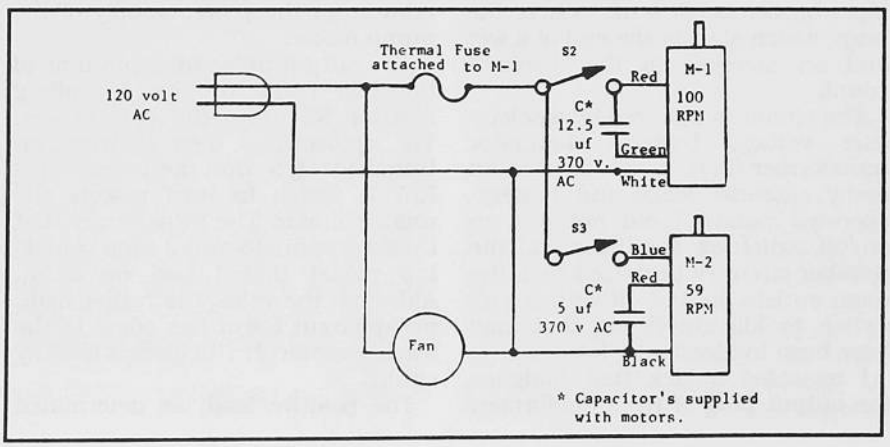
The electrical output of the grinding timer controls a method drives a Ford Motorcraft WG-40 windshield washer pump. This pump needs at least one ampere at 12 volts to operate. The output of the 556 could not drive all the devices it currently operates (i.e. the op-amp, the piezo buzzer, and the 7490) as well as a motor control relay. It can drive an optocoupler that drives the relay from the power supply of the pump motor.

The output pulse from pin nine of the 556 runs through a limiting resistor R21 into the optocoupler. The optocoupler then switches on transistor Q3 that actuates relay RLY-1, which in turn powers the washer motor. The transformer that I used was an 18-volt 2-amp center-tap model that I had on hand. Although the voltage is rather high, no apparent harm has come to the washer motor. It still gives a healthy squirt.

The positive lead, as determined







by banded sides of the diodes D2 and D3, goes to the center pin on the pump motor. The ground lead from the normally open contact on RLY-1 goes to the outermost pin on the pump. Be certain to flow solder all over the copper circuit board connecting strips that join the transformer to the relay and out to the pump motor. This is necessary because the pump pulls a healthy amount of current and the thin layer of copper on the board itself could burn out.

I used a 3/4-inch to 1-inch sprinkler pipe elbow from the input

Electronic Parts List

S-1	SPDT Momentary push-button	(275-1549)
S-2,3	SPST Toggle switch	(275-651)
RLY-1	5 volt SPDT Relay	(275-243)
IC-1	7805 5 volt regulator	(276-1770)
IC-2	556 Timer	(276-1728)
IC-3	741 Operational Amplifier	(276-007)
IC-4	7490 BCD Counter	(276-1808)
IC-5	7447 BCD to 7 Segment Driver	(276-1805)
IC-6	TIL-111 Optocoupler	(from 276-139)
Q1-3	MPS2222A NPN Transistor	(276-2009)
D-1	50 PIV 1.5 amp rectifier	(276-1151)
D-2,3	1N4001 Diodes	(276-1101)
D-4	1N914 Diode	(276-1122)
LED-1	LED Red	(276-033)
LED-2	LED Red with holder	(276-068)
LED-3	Common-anode LED display (substitute RCA #SK2052 if unavailable)	(276-053)
C-1	1000 mfd, 16 volt capacitor	(272-958)
C-2	.1 mfd capacitor	(272-1432)
C-3	220 mfd, 16 volt capacitor	(272-956)
C-4	22 mfd, 16 volt capacitor	(272-1437)
C-5,6	.047 mfd disk capacitor	(272-134)
C-7,8	10 mfd, 16 volt capacitor	(272-1436)
C-9	1000 mfd, 35 volt capacitor	(272-1032)
R-1	20K 15 turn resistor	(271-340)
R-2	1 Meg Potentiometer	(271-229)
R-3	470K 1/2-watt resistor	(271-053)
R-4	1K 1/2-watt resistor	(271-023)
R-5,6	100K 1/2-watt resistor	(271-045)
R-7,22	4.7K 1/2-watt resistor	(271-030)
R-8	330 ohm 1/2-watt resistor	(271-017)
R-9	47K 1/2-watt resistor	(271-042)
R-10,23	68 ohm 1/2-watt resistor	(271-010)
R-11	22K 1/2-watt resistor	(271-038)
R-12-18	270 ohm 1/4-watt resistor	(271-1314
R-19,20	10K 1/2-watt resistor	(271-034)
R-23	270 ohm 1/4-watt resistor	(271-1314)
T-1	18 volt 2 amp transformer	(273-1515)
P-1	AC to DC Battery Eliminator	(273-1650)
PZ	PC Mount Piezo Buzzer	(273-065)
M-1	100 RPM Gearmotor (Jerryco #5086, $27.50.	
M-2	59 RPM Gearmotor (Jerryco #2822, $13.50)	
M-3	WG-40 Ford Motorcraft Windshield Washer Pump (Ford dealership part, approximately $23.00)	

Jerryco's address is: Jerryco Inc., 601 Linden Place, Evanston, Illinois 60202)

Other items needed: Circuit board (#276-168) for timer, smaller circuit board for power supply for washer motor, experimenter's boxes (#270-627 for timer and #270-222 for washer power supply), jacks and plugs, IC sockets (one with 14 pin wire wrap with extended leads, #276-1993, for display), hookup wire, standoffs for circuit boards.

Aquarium airhose, 24 inches of rigid 1-inch uplift aquarium tubing, aquarium air valves, aquarium air pump, and foam air bubbler. Pulleys as necessary.

port of the pump. This has a rubber gasketed strainer on it, but the 3/4-inch end is tight enough to assure a leak-free fit and it comes apart for cleaning. To the upright 1-inch portion of the elbow I silicon-glued a 24-inch piece of clear, rigid 1-inch uplift tubing as used in aquarium sets.

The output of the pump goes through about five feet of tubing to a small plastic aquarium air-control valve that has interchangeable tees and fittings which allows you to disconnect it for cleaning. It is located about 18 inches above the polishing surface, on the counterbalance upright, and on through another short length of tubing to the swinging arm that holds the tool during polishing.

The pump discharge is determined by the grinding timer. It lasts for approximately 3 seconds and discharges 1/4 teaspoon. During this interval the arm goes back and forth across the mirror, so some portion of the output sprays onto the mirror.

To keep the cerium oxide from settling to the bottom, I used a small aquarium air pump to keep the cerium oxide in suspension. I use about one teaspoon per fill in the uplift tube. The air-pump output goes through a section of aquarium air tubing to a foam-type bubbler placed in the bottom of the upright tube holding the water/cerium oxide mixture. This method keeps the cerium oxide well agitated and keeps it blocking the pump up. It also keeps the polishing liquid uniformly mixed.

Polishing with the Machine

The lap that I currently use to flash-polish is made with number 8XX polyester multifiliment silkscreen cloth obtainable at most art supply and drafting supply stores. It wears well and does not seem to hop and skip as much as when netting or screening is used. I simply rubber band the silkscreen fabric onto the tool, which is usually Pyrex, trim off the excess fabric, polish for approximately four counts of the grinding timer with 5-micron aluminum oxide, reverse tool and mirror positions, and resume for four more counts of the timer. Each four-count interval is approximately 13 minutes.

At this point I place the mirror on the bottom, put the tool with its screen in the swinging arm on top, plug the polishing pump into the grinding timer via the jack on the side of timer, and polish for two hours with cerium oxide. I check the cloth for wear or tear every 45 minutes or so. If some greyness exists in the middle of the mirror, this will usually disappear if you reverse the positions and polish with the conventional mirror-on-top method. This usually results in a polished surface that you can readily check on a Foucault tester to determine your radius of curvature.

I do not remove the silkscreen that contained the 5- micron powder but continue with it because most of the 5- micron powder is broken down at the end of the polishing period, anyway. This method is only regarded as a "flash" method only (i.e. it arrives at a polish faster than utilizing cerium oxide alone).

I have become so certain of the action that I now plug the turntable's motor, the swinging arm motor, the timer, the aquarium pump, and polishing pump power supply into an appliance timer and let the whole apparatus run by itself for a couple of hours while I go off to work. When I return home, I separate the lap and mirror, re-wet it manually, and polish a few more strokes to remove any residual oxide that may have superficially dried to the mirror.

I do final polishing with a subdiameter pitch lap. I cut grooves with a high wattage soldering gun that has a tip ground to a width of 0.080 inch. I correct defective grooves by melting pitch onto the lap from "sticks" of pitch made by pouring melted pitch into long thin trays of aluminum foil. Trimming still seems to call for the 1-inch wood chisel. The spattering from the soldering iron is messy and is best done with rubber gloves, but seems to produce laps whose facets do not come off and do not chip as much as with saw-cut laps. I still recommend hot and cold pressing the pitch lap with netting.

If you decide to use the turntable to speed up the process of final figuring (as with larger diameter, short focal length mirrors), I would use a subdiameter star lap with a depressed center (lap on top method with shorter strokes). The depressed center (often no more than the thickness of aluminum foil) keeps you from digging a hole in the center of the mirror. The final figure is polished in by the standard hand methods.

The overall cost of the machine was well under the difference between the cost of a 10- or 12-inch kit and the price of a commercial mirror. I am now using this machine for a Yolo telescope. The pictures of the machine show it polishing the easiest part of the job—the 5-inch primary mirror!

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ASTROFEST 1989

Plink. Plink. Plook. Plink. It must have been three in the morning. I woke up wet in a gentle mist of water. As the rain poured down on the roof of my van, water ran in rivulets down the rear doors, trickled around slightly open window, and splashed gently on my face. Plonk. Still groggy from the six-hour drive through backed-up Friday-night traffic around Chicago, I rolled over and tried to doze again. Plink. Plunk. Plunk. Ploop!

I sat up. It looked like Astrofest was in for a soggy year. Even though I had parked under a big tree, the canopy of leaves afforded no protection; rain drummed steadily on the thin sheet metal. I groped for the latch and pulled the window latch shut. "Grump, grump," I thought, "grumpitty, grump, grump." I was awake now, and there was no escaping the need to pull on some clothes and trek.

When the rain slowed, I squished across the boggy sod toward the washrooms. It was comfortably warm out and, if I hadn't minded being wet, quite pretty. Droplets sparkled on the grass and in the trees under the pink radiance of Camp Shaw-Waw-Nas-See's sodium lamps. No one minded — no one was observing! How, I wondered, will anyone set up a telescope when day arrives?

I woke again with the early morning light, stretched, and tugged on damp clothes. Nothing in the van was really dry save my cameras closed in ziplock plastic. Outside I heard the burble of voices as campers stirred and Astrofest 1989 got under way. I squished off in search of coffee and donuts.

Well, the long and short is the Astrofest spirit triumphed. These folks came for an astrofest, dammit, and they were going to *have* an astrofest come rain or shine. Take the swap meet, for example. By 7:30 the first tables had been set up, and by 8:00 the affair was in full swing. It was not scheduled to begin until 9:00. Talk about eager beavers — these Illinoisans, Michiganders, Wisconsonites, Hoosiers, Iowans, Ohioans, and Mizzoura'ns *just couldn't wait.*

A light breeze sprang up early Saturday morning and soon the telescope field was dry enough for telescopes. In short order telescopes appeared from vans, from under tarps, from trunks, from trailers, and from roof-top carriers. Stationary vehicles were fine, but moving vehicles often cut through the turf, got bogged down in mud, and had to be pushed out. Although it looked for a while like the sky might clear Saturday afternoon, the rain returned Saturday night.

One of the first telescopes up — it was there the first time I looked across the telescope field that morning — was Bill Volna's portable observatory. Volna showed this telescope at Stellafane last year, and I've tried to get him do a write-up for *TM*. Seeing his telescope in person was the next best thing; it is an impressive piece of work.

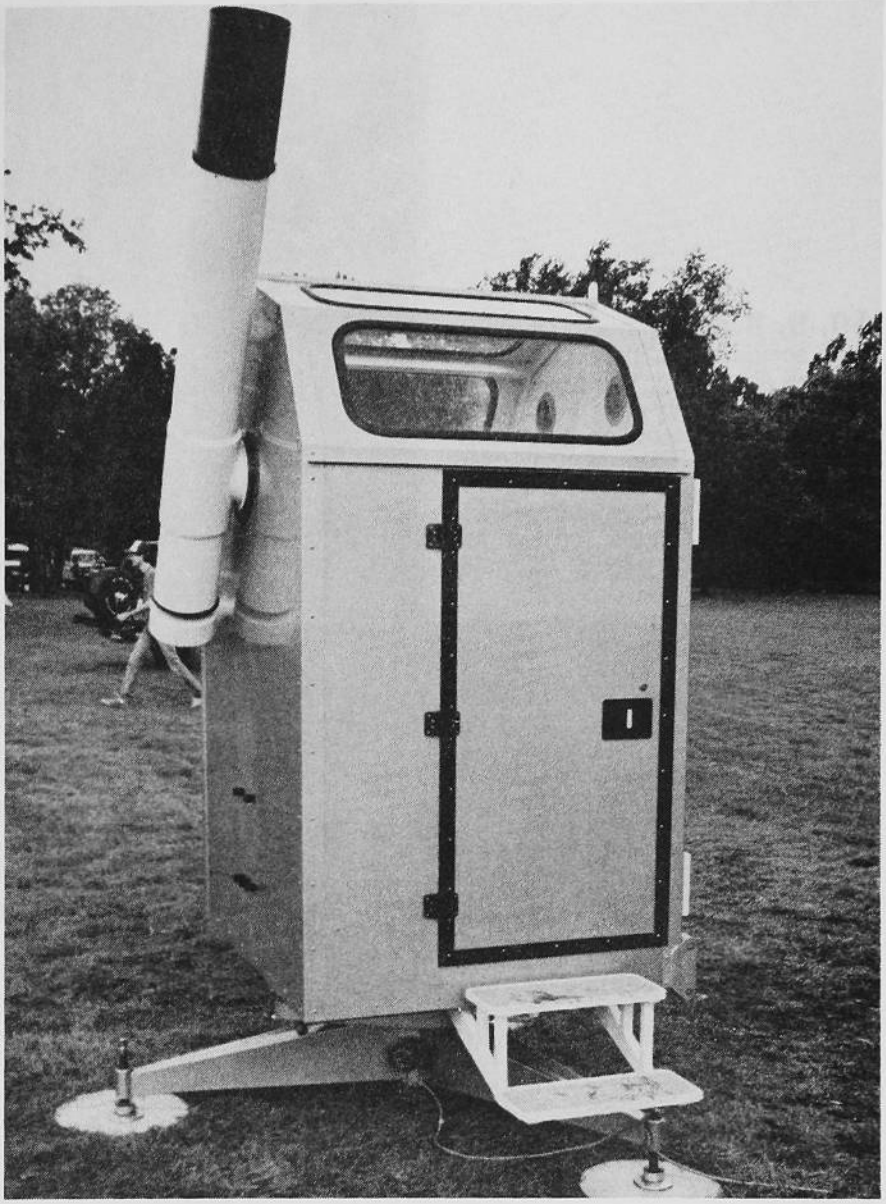
What Volna has done is mount a 6-inch f/10 refractor on the side of a small observing cabin. The cabin is mounted altazimuth, of course, and carries in it all of the comforts of home. It is heated, has both red and white lighting systems, sky viewing windows, a convenient desk surface, a built-in thermostat-controlled heater, and a comfortable contoured bench for the observer to sit on. In the year since he built it, Volna has observed when the temperature was −17°F — typical Minnesota clear-sky winter weather.

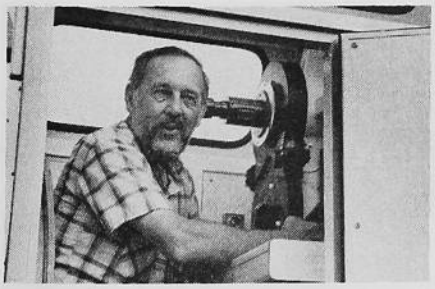
An engineer by profession, Volna designed and built virtually every component of his portable observatory, right down to the hinges and latches on the doors. Paging through his notebook was a treat because he has taken dozens of pictures that show the observatory at every stage of construction. These reveal that the cabin frame and its three-legged base are weldments and that all parts of the "running gear" are machined.

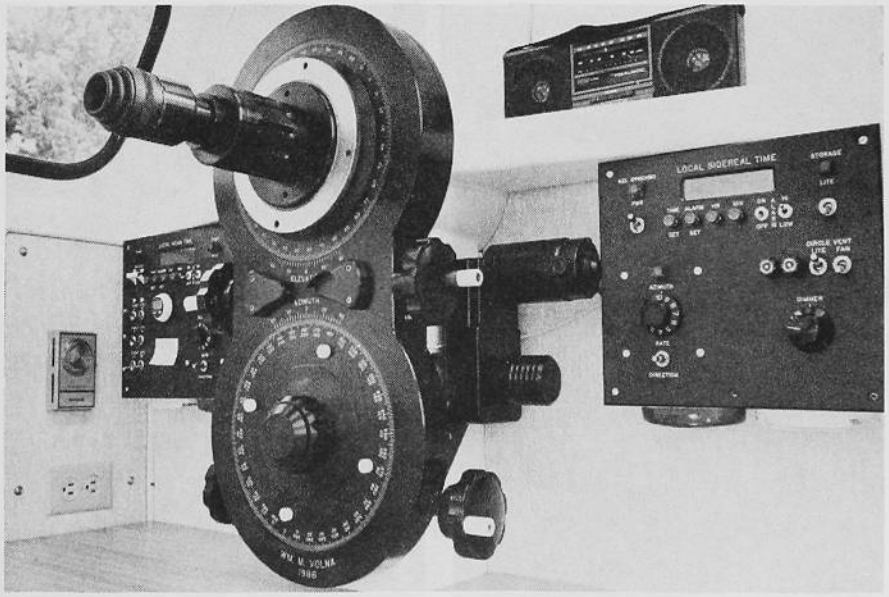
Well, there it was in front of me. I couldn't resist: I climbed in and sat behind the eyepiece at the controls. Centered in front of me was the big "grandfather clock" that holds the telescope. The telescope is mounted in the center of the altitude ring and held in place by a large threaded ring of stainless steel or something that looked a lot like it. Volna confirmed to me that if I unscrew the ring, the telescope comes out.

Large knobs protrude either side of the grandfather clock below the altitude circle. Turning this moves the telescope in altitude at a rate of 4° per turn. The circle is graduated in degrees and can be read to 5' with vernier scales. A small red light illuminates the

Beneath the altitude circle on the grandfather clock is the azimuth



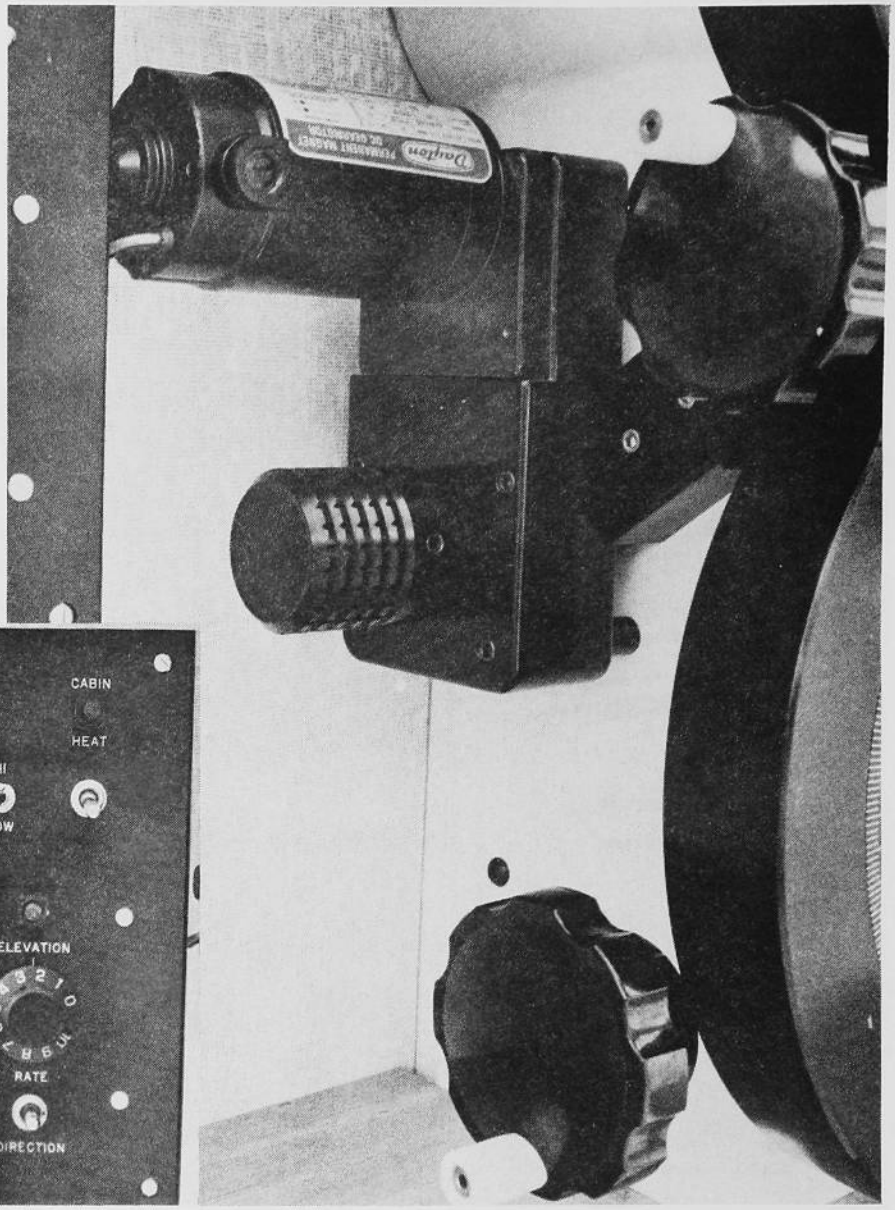


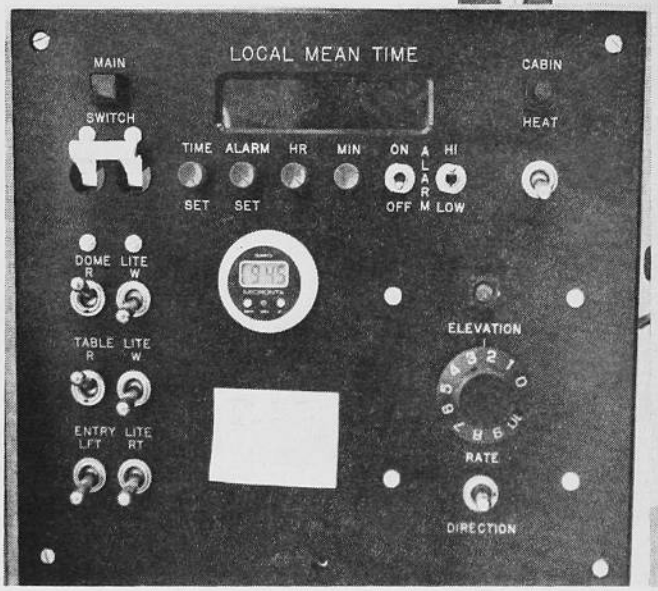


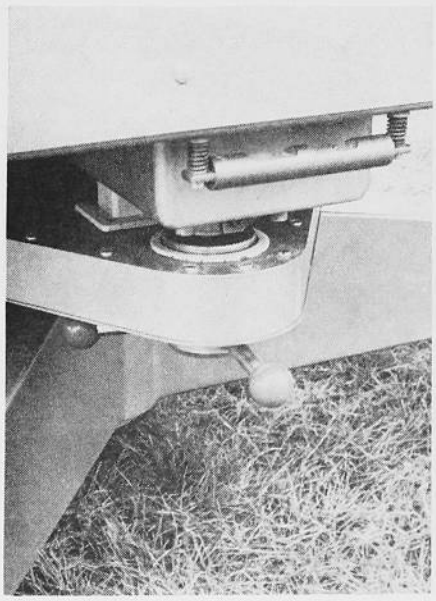
SNUG AS A BUG...
in his heated altazimuth observatory, Bill Volna (seated at the controls) demonstrates tracking with manual controls. With drive motors running at the instantaneous rate of motion in each axis, Volna can track an object at high power. Only near the zenith is he limited by his observatory's tracking ability.

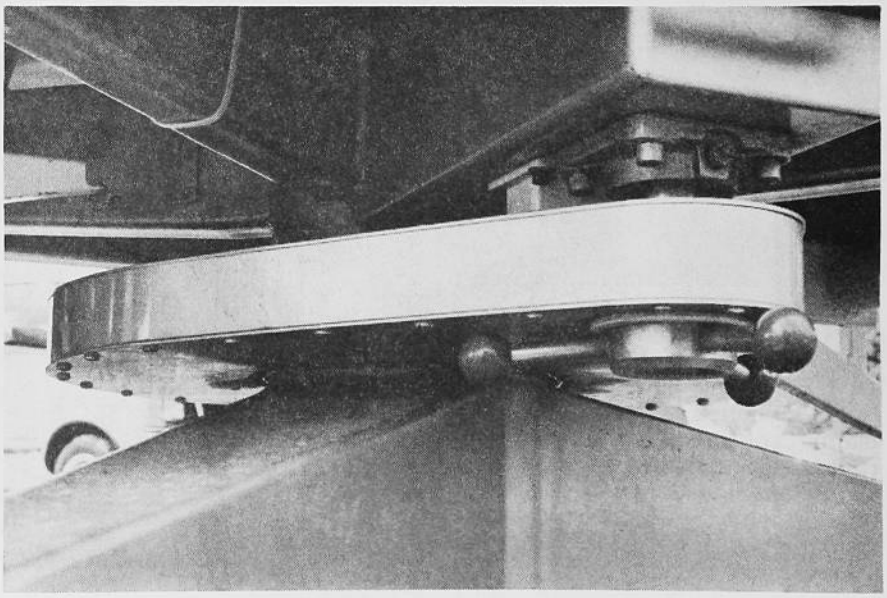
10, 9, 8, 7, 6, 5...

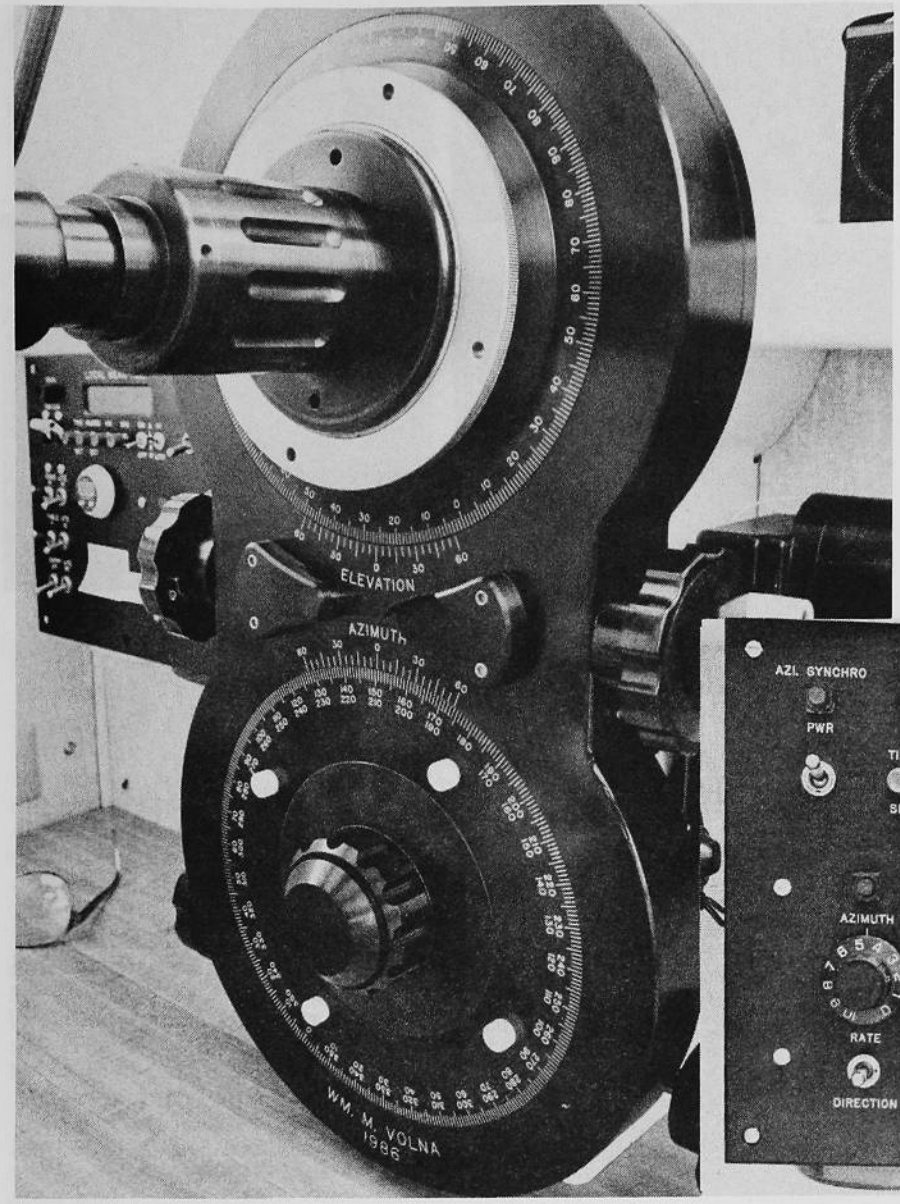
With seemingly as many controls as a small spaceship, Volna's observatory allows the observer to tailor his or her environment for comfortable observing. Switches control every electrical function while seated at the eyepiece. Drive motors and clutches are located behind the grandfather clock, against the wall.





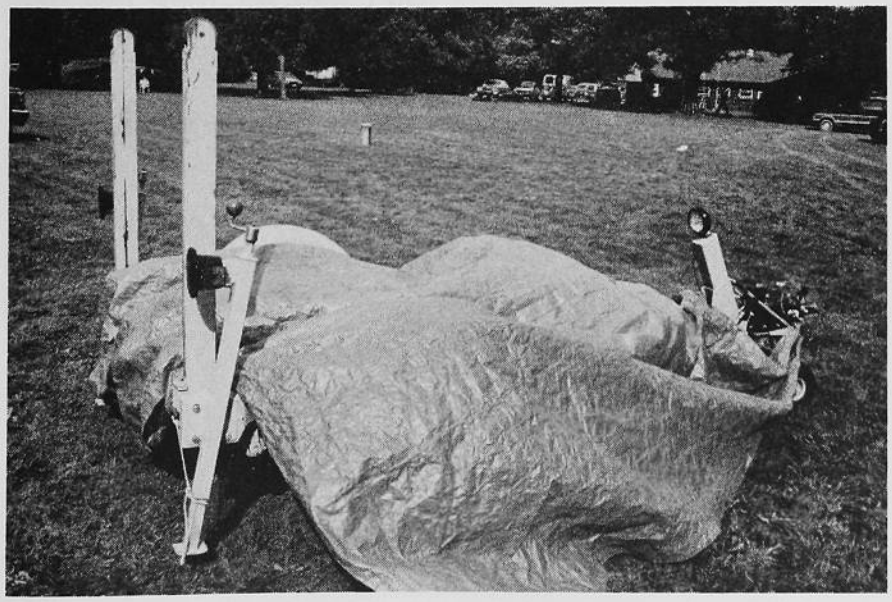


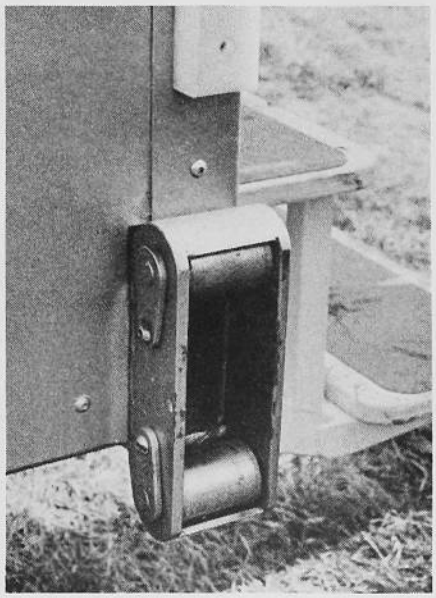


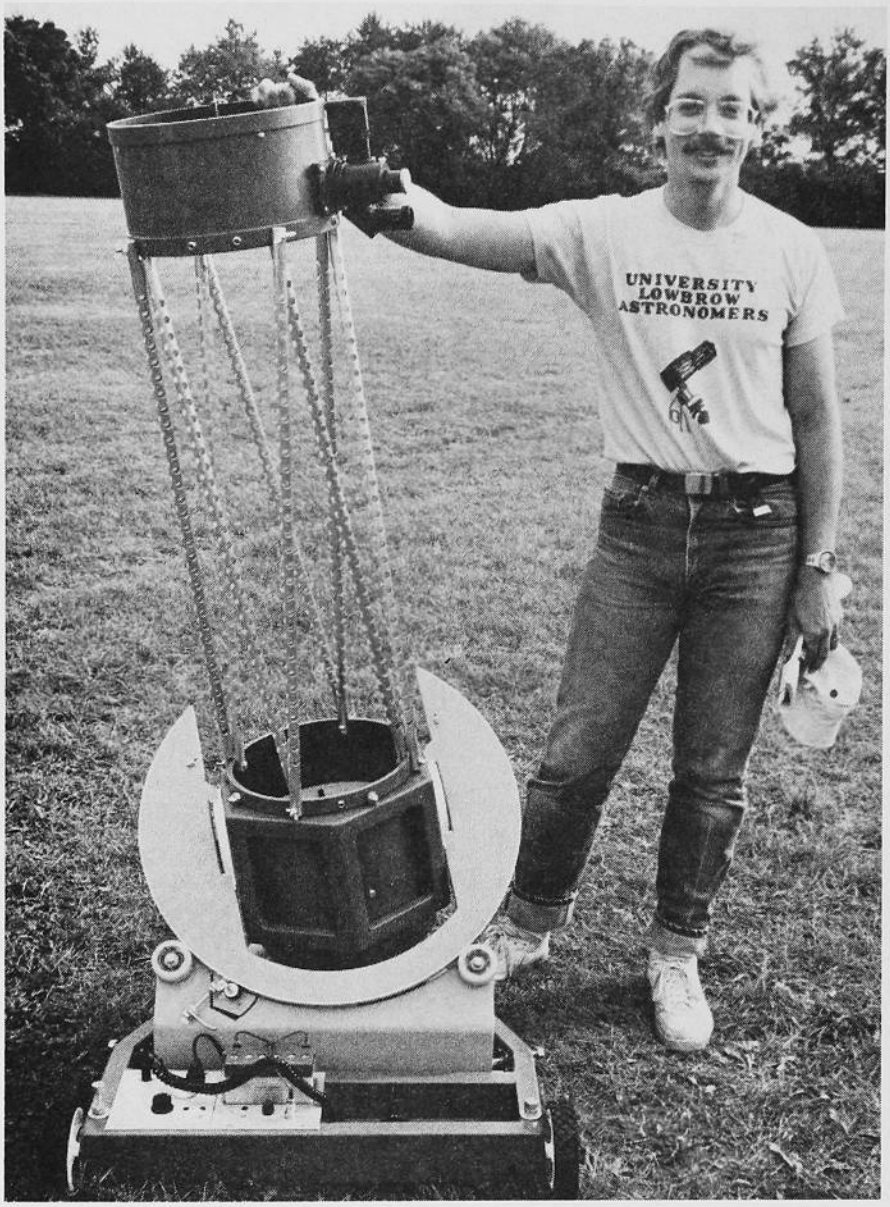


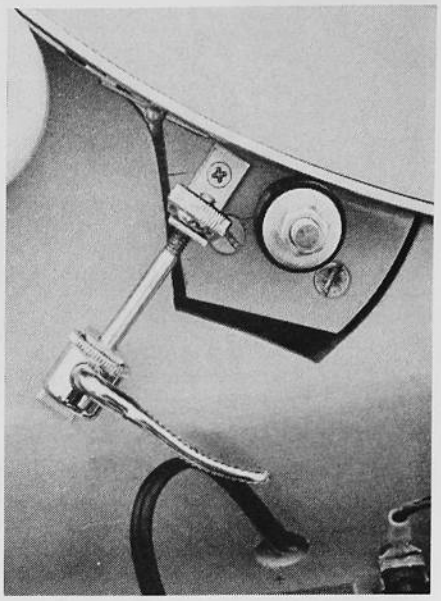
UNDERNEATH IT ALL...

The observatory rests on a heavy welded tripod and is turned in azimuth by means of a heavy bicycle-type chain between a drive gear and a large stationary sprocket gear. For trailer transport the two upright steel bars slide into holes in the observatory, then tip the entire structure on its side.

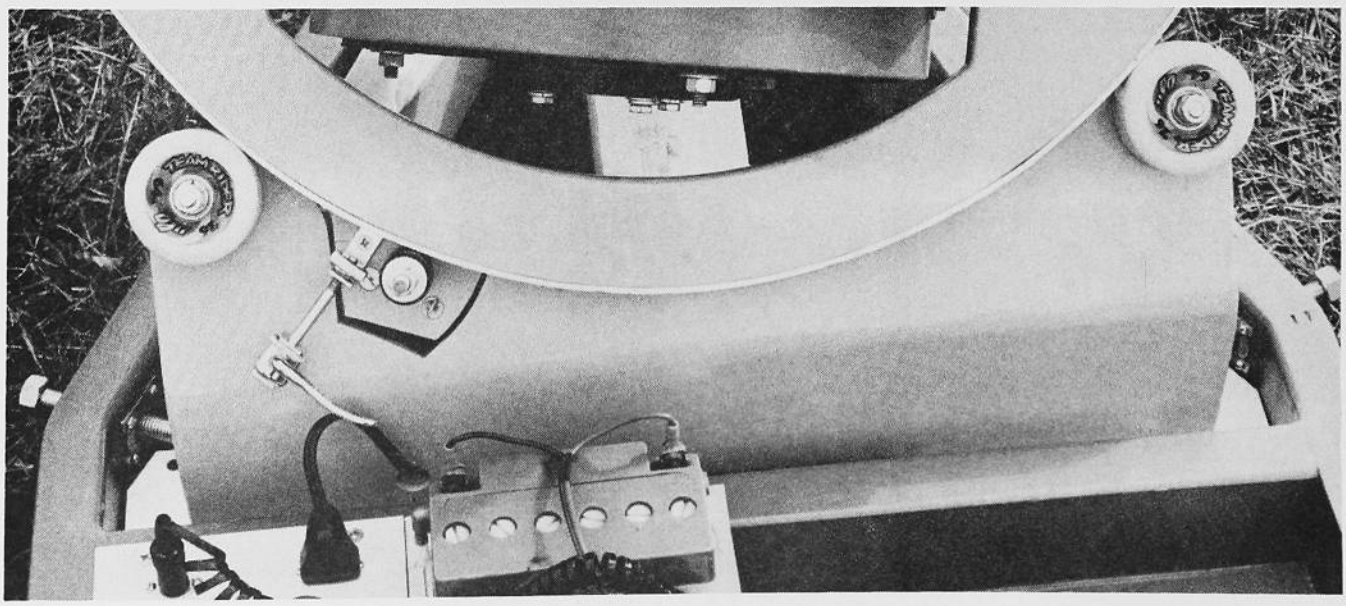


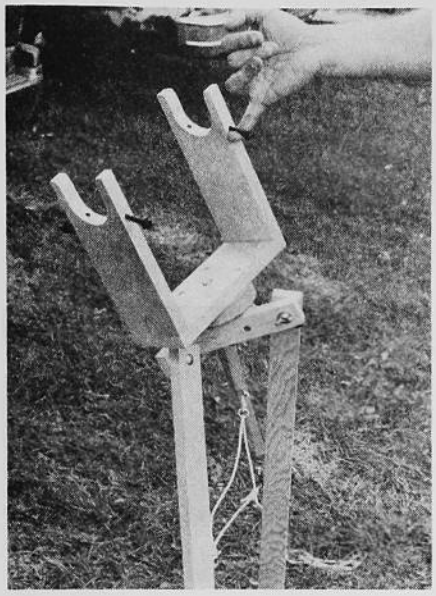


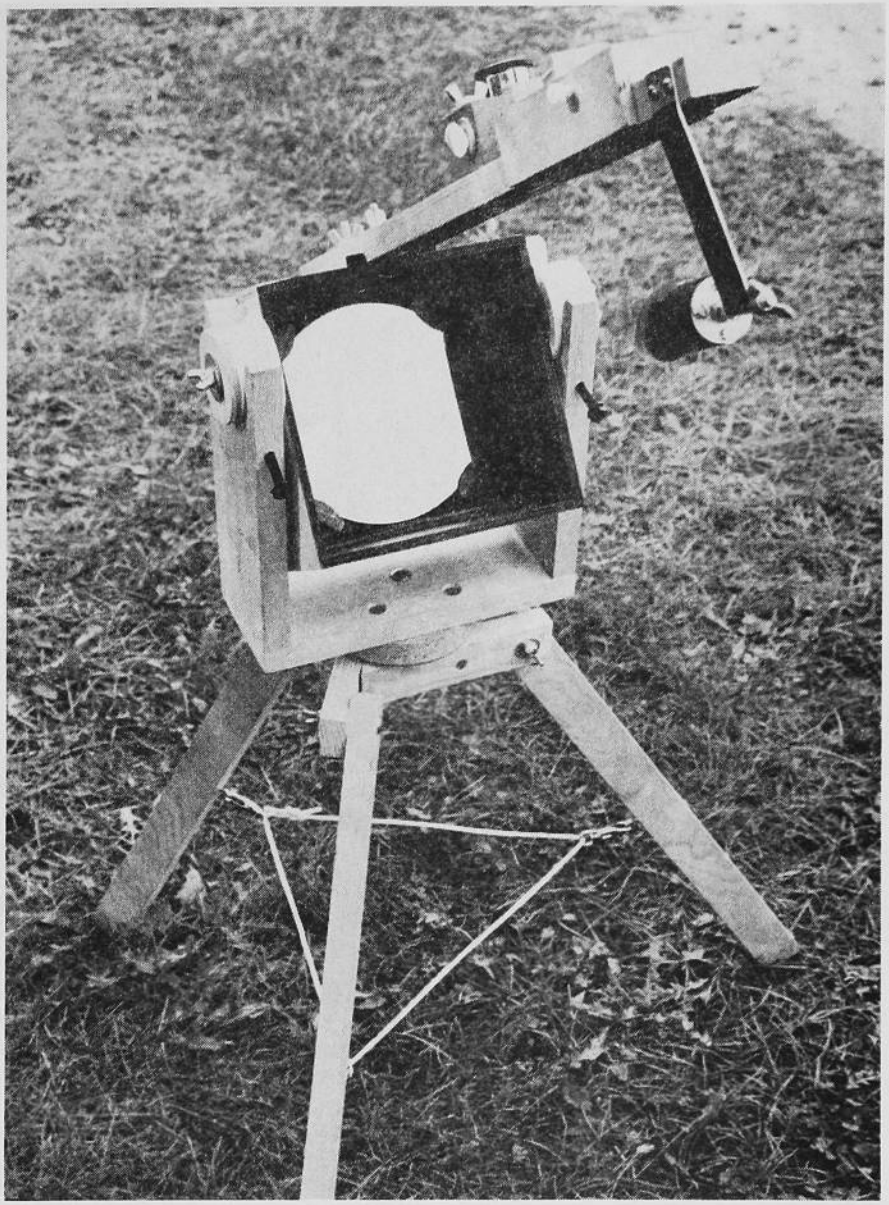




LIGHT AND PORTABLE...
When you're going somewhere with a telescope, lightness counts. Fred Schebar removed half a pound of aluminum by drilling holes in the struts of his 10-incher and saved five pounds in counterweights. Thane Bopp carries these knock-down 6-inch and 8-inch telescopes around the world in his luggage.







circle. It, too is graduated in degrees and is the readout dial for a slave servomotor. (The sending unit is in the base.) This ring can be unclamped and reset to the correct azimuth at new site. A vernier scale reads to 5', but the servo resolution is roughly 15'. The knobs move the telescope at a rate of 1° per turn in azimuth.

Behind the clock are two motor drive units. The one on the left drives the altitude axis; the one on the right, the azimuth. Both are driven through timing belts. On each motor-drive unit is the motor itself and a clutch with three positions: high speed, low speed, and freewheeling for manual control. The high speed is 36 times faster than the low speed, and the rate for each motor can be set on control boxes on each side of the grandfather clock.

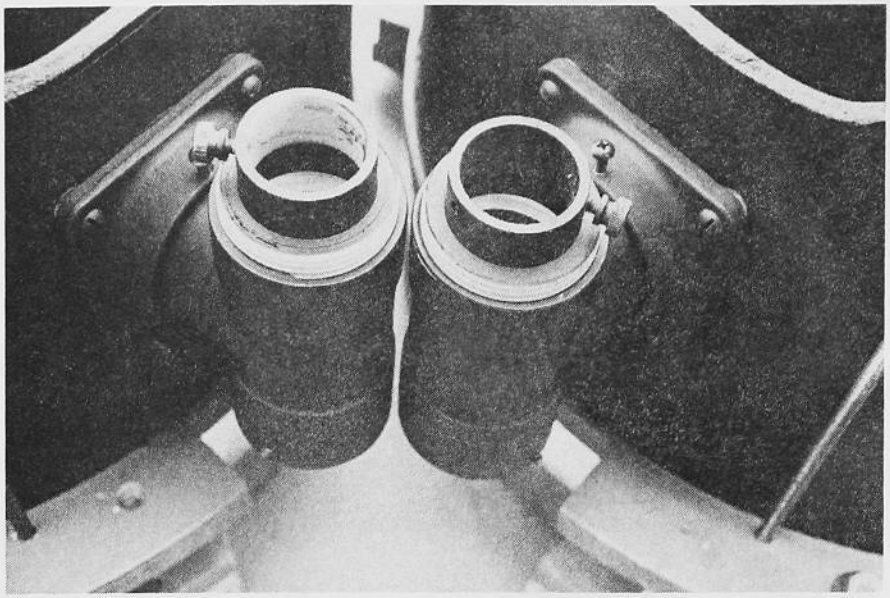
Between the clutch and motor rate adjustment, Volna gets a speed range of 10,000 to 1 on both axes, so he can slew rapidly to a given altitude and azimuth and then dial in the right rates to track an object at high magnification. Although this arrangement wouldn't do for photography, it's probably great for visual observing.

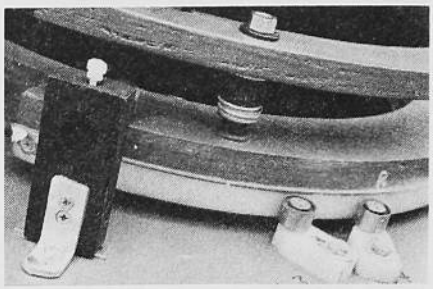
Volna set out to build a complete observing system, which includes arrangements for transportation and set up. It was immediately obvious that the observatory rode a small trailer, but loading it would seem to call for a lot of grunting and groaning, so I said so. Volna was clearly amused and showed me the trailer. "You got these two peckers here," he said, pointing to two upright heavy steel bars, "and the other part is on the telescope."

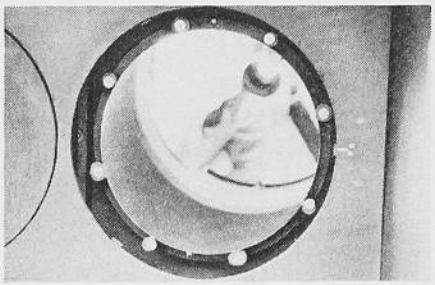
I looked — sure enough, there are receptacles for the "peckers" on the side of the observatory. Volna lowers the peckers to a horizontal position, rolls the trailer backward to the observatory, and prangs it. He then actuates a hydraulic cylinder that rotates the peckers to a vertical position, tipping the observatory over on its side. After a few quick tie-downs, he's ready to roll.

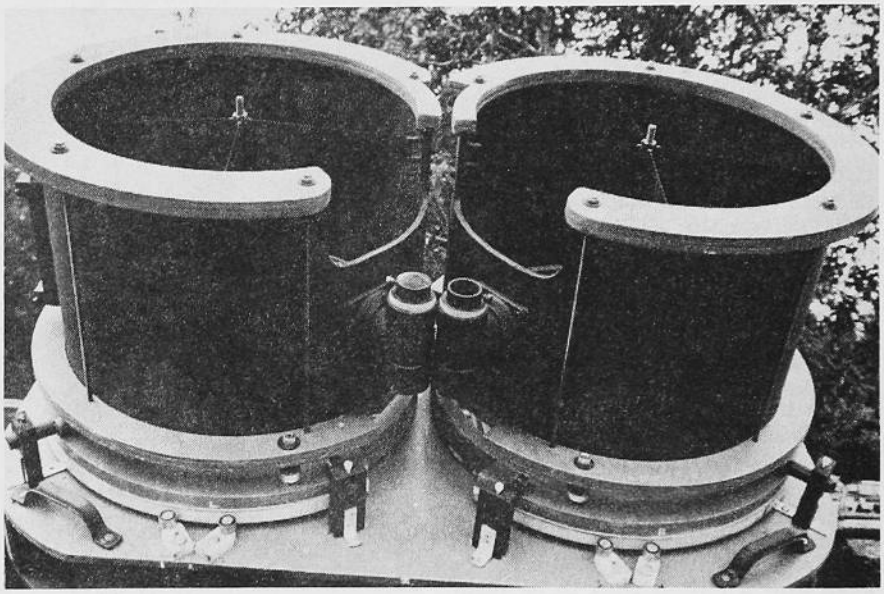
Bill Benesch of Naperville spent his Saturday watching the sky for clear spots — "sucker holes" — so that he could demonstrate the exceptional performance of his folded Daley solar telescope. "You'd be dazzled looking through this scope," he said staring at the gray sky, "you'd just be dazzled."

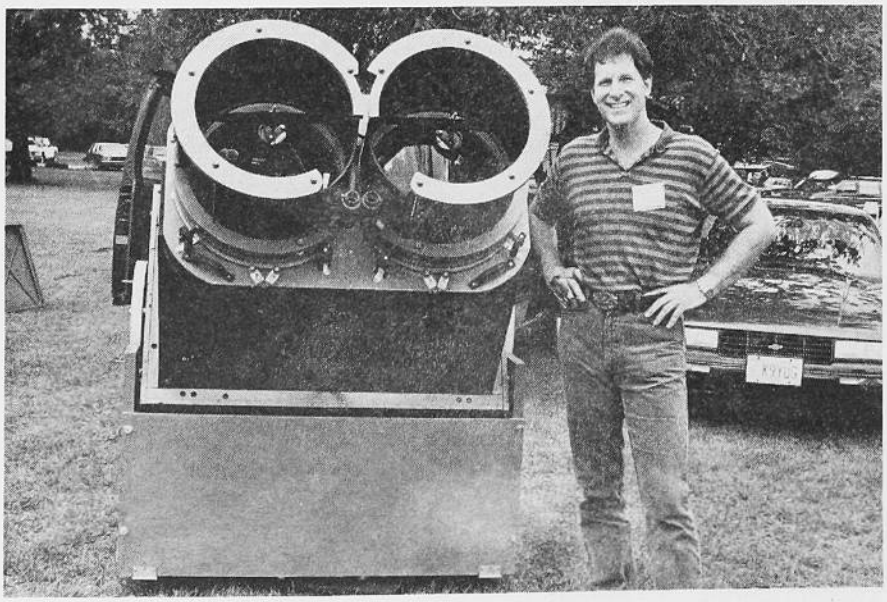
In this instrument, an Inconel-coated precision optical window reflects almost all the Sun's light back to the sky — all but 1 part in 10^5 that passes through to a paraboloidal primary mirror that reflects the light back toward the window; the window reflects the image back to focus beside the mirror. This system, because it is both unobstructed and closed, gives exceptionally high-quality images of the Sun. Benesch said he got the idea from *Amateur Telescope Making Advanced — Optics*, page 213. He made both the primary and the fil-



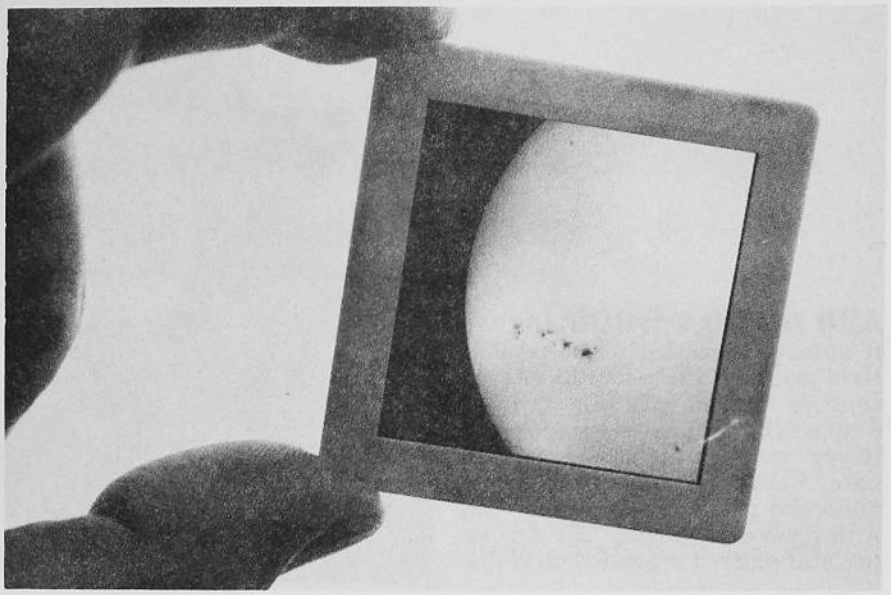


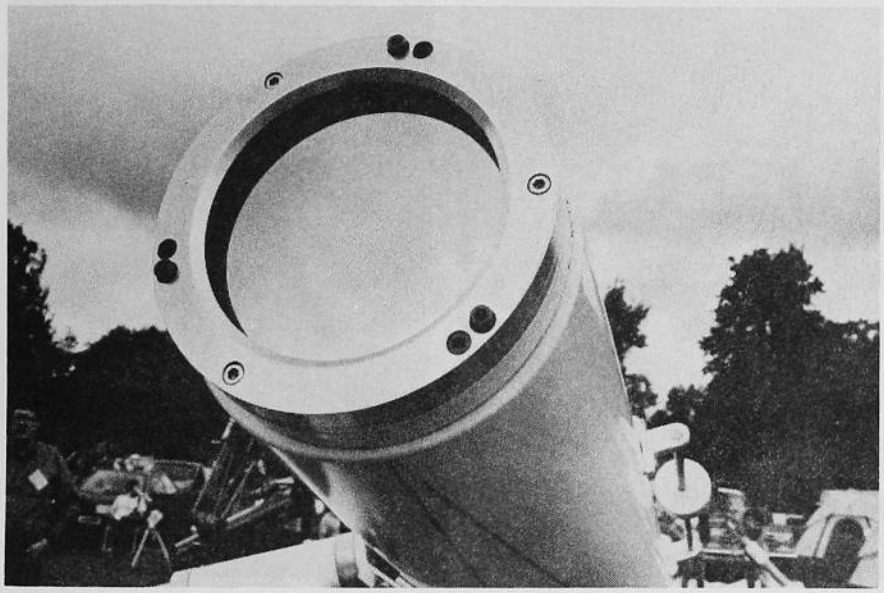


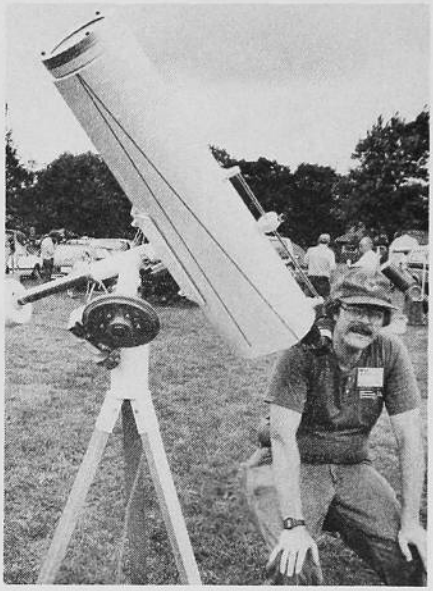


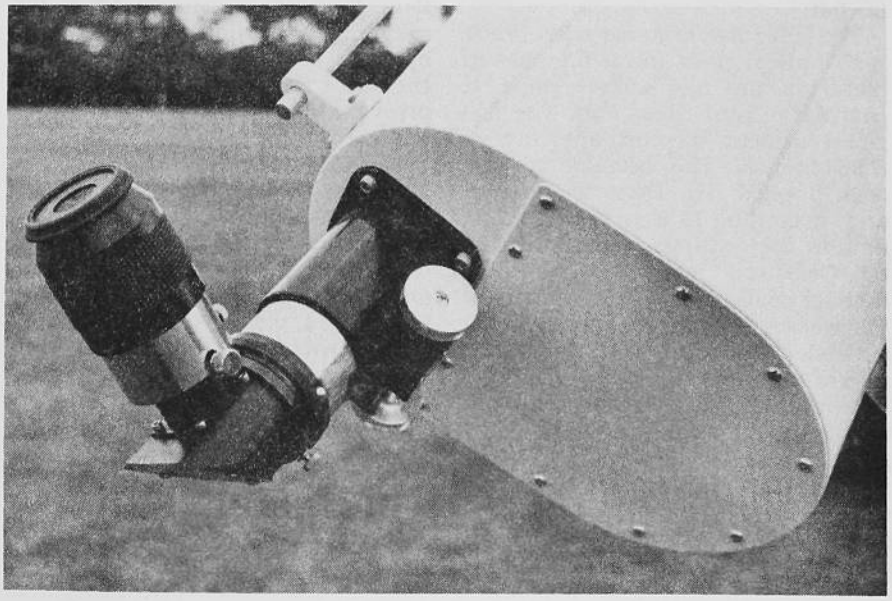


SEEING DOUBLE...
Individually adjustable front ends give Doug Kasel a reliable 16-inch binocular telescope. Cams and rollers hold each upper-end unit firmly in the right place, and allow easy setting of the interocular distance and collimation that stays put. The telescope was tested only briefly before Astrofest, but it worked.

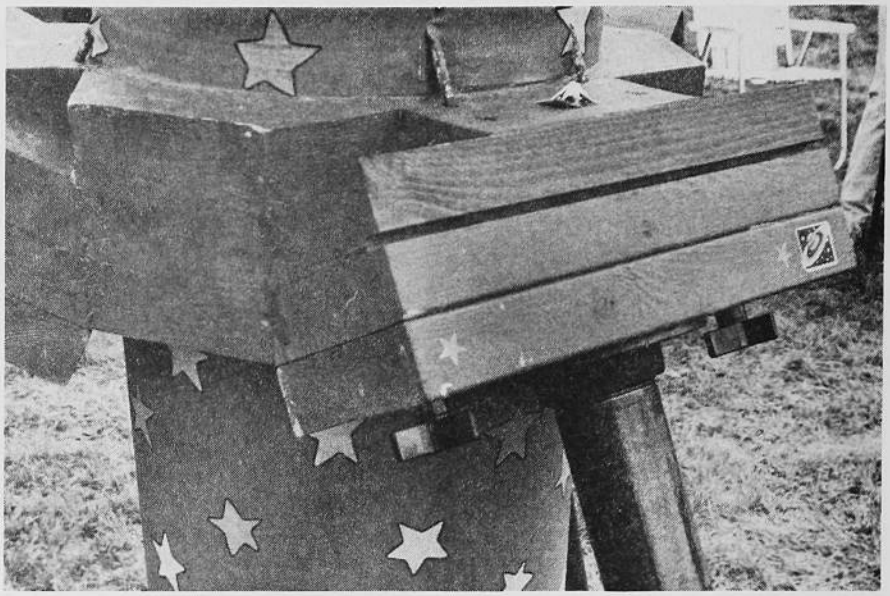




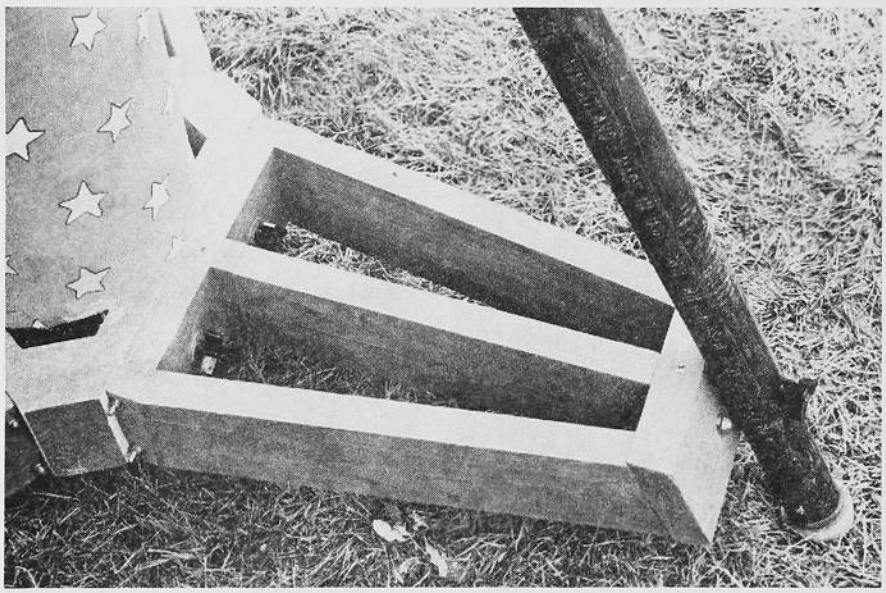




SEEING DIMLY...
Thirteen centimeters of diffraction-limited solar aperture enclosed in a fiberglass tube – but no Sun for the folks to look at! Nonetheless, Bill Benesch's f/15 Daley-type telescope looked great and he had beautiful solar slides he had taken by afocal photography to show off. A great project for solar-max year.



APO DOB ON WOOD...
It stood out on the telescope field head and objective above its shorter cousins — Alan and Sue French's 8-inch f/11.5 Christen apochromat. Heavy wood-and-pipe knock-down base supports 12-inch diameter Sonotube pier, reinforced internally with plywood triangles. The decorative star pattern is printed on cloth.



ter flat.

The filter flat is made from grade A K7 optical glass and is 6 inches in diameter and 3/4 inches thick. It cost $100 from Glass Fab. The finished system has an aperture of 5.25 inches. The Inconel coating was applied by Denton vacuum and, according to Benesch, is identical to the coatings Denton applies to Celestron solar filters. The Inconel coating cost $129 and took 12 weeks; a magnesium fluoride antireflection coating on the other side of the glass cost $100.

In making the flat, Benesch used the techniques described in *ATM Book II*. The 24-step testing routine for flatness and his testing for wedge down to about half a ten-thousandth of an inch, he feels, were responsible for an excellent flat. Benesch recommends a dewedging technique in which the optician uses his thumb, opposite the thick side of the wedge, as a pivot during the last few minutes of a wet when the grit is very fine.

Benesch also made the beautiful fiberglass tube. He made two halves of the the tube in females molds, then cut them and joined them with thick resin per instructions in *Amateur Telescope Making Advanced — Mechanical*, page 198. For attaching components, he glues T-nuts into the interior with resin and a little square of glass cloth.

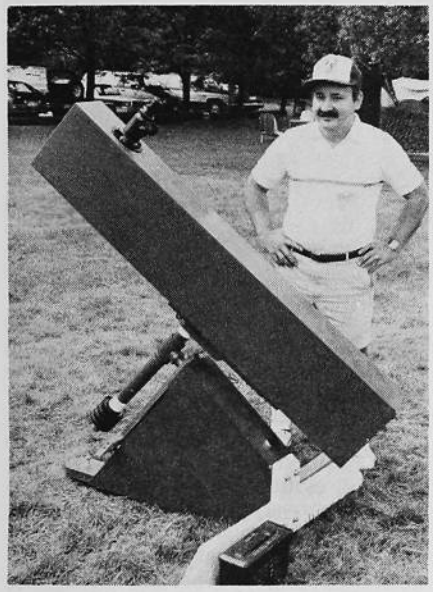
David Kriege of Lake Mills set up telescopes of 18-, 20-, and 25-inch aperture under a tent that seemed to have acquired a nickname: "The Kriege Pavilion." Obsession 2, the 25-incher, can be set up in five minutes because it uses a clever system of twist-lock poles to support the upper end. Obsession 3, his latest creation, boasts an exceptionally fine 18-inch mirror. Kriege has extended his search for the perfect Teflon, and found that Wilsonart 4552-50 countertop covering — a rather rough pebble-textured material — has one-third the friction against Teflon of conventional Formica bearings (see *TM#35*).

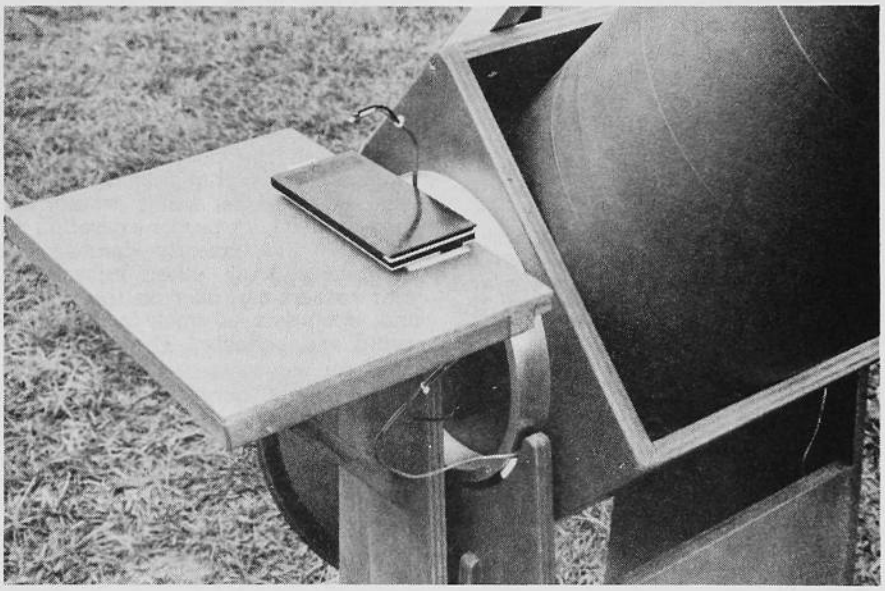
Another Kriege technique is to place a central Teflon pad in the azimuth bearing. This pad can be jacked up to reduce the weight on the other pads — and thus reduce friction — without itself adding significant torque. The result is that his big telescopes move as smoothly as well-made small Dobsonians.

Finished just the week before

...AND MUCH MORE

Many telescopes probably stayed under cover this year, but two that came out were Perry Moon's 10-inch f/5.6 Dob fitted with a handy side table (better for a 10-inch than the "rooster-tail" tables that work so well on 17-inchers) and Ed Jones' 6-inch Herschelian cat. See page 10 of this issue for a full description.





Astrofest was Doug Kasel's massive 16-inch binocular. Kasel solved the tricky problem of aligning two 16-inch optical systems with independently tiltable and rotatable upper-end units. For longitudinal control of the upper ends, he uses nylon buttons. For axial control the rollers are mounted on swivels and can be adjusted precisely. To prevent side-to-side motions of the primaries, Kasel grips them quite closely with eccentric cams. Kasel reported that in a test run the telescope had performed as planned — "it focuses, merges, and stays put" — and that he was very happy with it.

Fred Schebar of the Lowbrow Astronomical Society (Ann Arbor) showed a very fine 10-inch f/5.6 on a split-ring mount. With skateboard rollers and bicycle parts, Schebar constructed a clock drive that he says is both smooth and reliable. The skateboard wheels are heavy density ones — the densest available — and the drive clutch is a quick-release for a bicycle seat post. "Good mountain bikes have them," he told me. Anyway, the gadget pulls the driven rubber roller back for slewing and pushes it forward to engage the drive. His AC synchronous motor is driven by a dual 555 chip through a backwards 18-volt transformer. Overall, it's a nice job and it works.

Sue and Alan French displayed their massive Dobsonian refractor. The 8-inch f/11.5 instrument has an apochromatic objective made by Roland Christen. "It's roughly a super-planetary triplet," said Sue. A huge pier made of Sonotube, construction timbers, and 2-inch pipe supports the instrument's Dobsonian cradle roughly eight feet off the ground, but the telescope moves with the light touch of a finger.

In the evening after dinner, and after after-dinner speaker Steve Edberg reminded us of the scientific and commercial foibles of the Halley era, it began to rain again. I considered carefully how tired I was, how wet I was, and how wet the night might be — then climbed into the van and headed north again to Milwaukee — the first time I've bugged out early on Astrofest. But in spite the rain, the cloudy skies, and the sodden ground, Astrofest 1989 proved that amateur astronomy and telescope making are alive and thriving in the Midwest.

— Richard Berry

Letters

steps should be taken to stop the false advertising and false advertising is exactly what we are dealing with.

Taking the "extreme" measure should not unduly stress the industry as some will surely say. There is no need to ask manufacturers to produce what they advertise, just advertise what they produce. Edmund Scientific sells telescope mirrors with the claim of 1/8-wave or better surface accuracy. I can't say if they meet the claim but at least they are not afraid to advertise a surface under the magic 1/20-wave or 1/10-wave figures. Parks Optical is not afraid to make no numerical claim whatever. These companies may or may not produce superb optics, but their ethics at least are beyond reproach.

If all manufacturers were required to meet their claims (it would take very few stiff penalties to bring them all into line) they would not have to fear losing customers to still unethical competitors. Advertising claims would become more reasonable (truthful) on the standard line of optics and we would see many of the same companies producing a "premium" line at the necessary higher prices. Aren't these things the manufacturers and amateur astronomers both want? The real disgrace is that the present situation has been allowed to continue as long as it has.

Steve Davis
3276 Effinger Rd.
Wadesville, IN 47638

– What concerns me is who is the someone who would police firms that sell optical equipment. How would that someone monitor quality, and how would that someone impose penalties? Frankly, I don't think it's practical to impose controls on an industry from the outside. But– could the optical industry regulate itself, with an organization that would establish and maintain high optical standards among member firms? Readers: your input is requested.– RLB

Restoring a Refractor

Dear Sirs/ I have been an amateur astronomer for over ten years, and was recently sentenced to three years in Yankton Federal Prison Camp on a drug charge.

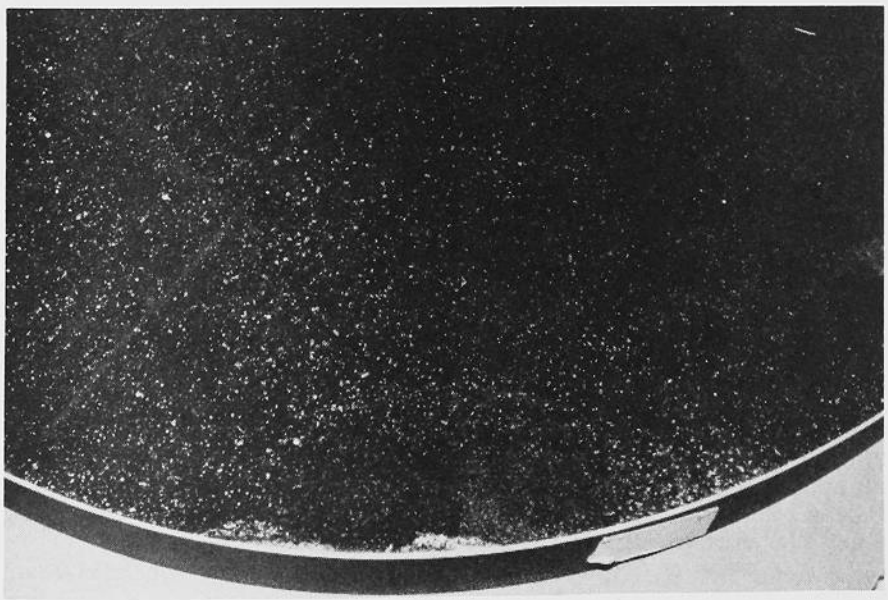
When I arrived I saw that there was an old observatory housing a large refractor telescope on the grounds. I put in a request to try and put the facility back in shape, and my request was granted. Now I would like to request some assistance from some of your readers who know something about the telescope that is in the observatory.

The telescope is a 7-inch refractor. The name plate on the rear says "Warner and Swasey." It has a mechanical clock drive, and I'm told that the telescope was built in the 1800s.

The project is starting now. We will renovate the building first, then put the telescope back in shape. The drive apparently works, but I would like some tips on its proper operation so we don't inadvertently damage the mechanism. Any other information your readers can offer on the upkeep and operation of such a telescope would be appreciated. Thanks–

Larry Rhoden
Box 340
12368-047
PMB 700
Yankton, SD 57078

–Can anyone help Larry? I'm sure we would enjoy seeing photos of the telescope and reading of its restoration.



Iowa Refractor Was Late Clark

Dear Richard/ The 12-inch Clark Corporation refractor described in *TM #37* is interesting in that it is probably one of the latest large refractors produced before the demise of the company. From the design details in the photos, my guess is that it was fairly new when it was donated to the school system in 1939. The instruments made by the company in this period are not well accounted for today.

Alvan G. Clark died in 1897: Carl A. R. Lundin in 1915 and his son, C. A. Robert Lundin, in 1962. The role of the Lundins in the making of many large "Clarks" has been understated. The Iowa refractor, which was probably made after 1931 when Lundin, Jr. left the firm, is evidently the product of an even more obscure optician.

But that does not mean it's not an excellent instrument. Congratulations to the Southeastern Iowa Astronomy Club for having salvaged another forgotten telescope!

John W. Briggs
100 Oak Rim Way, 11C
Los Gatos, CA 95032

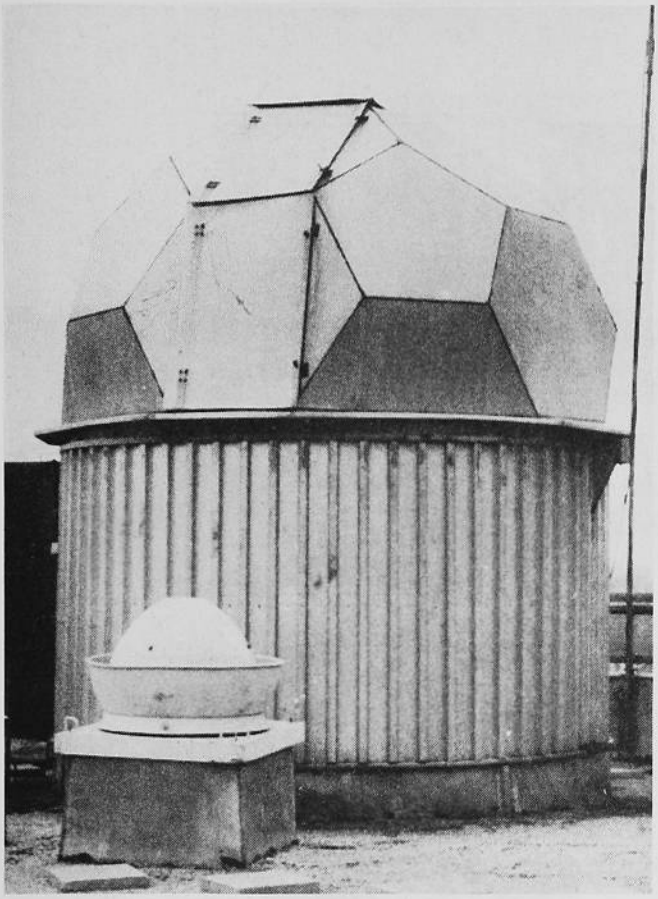
WSP Seeing Superb

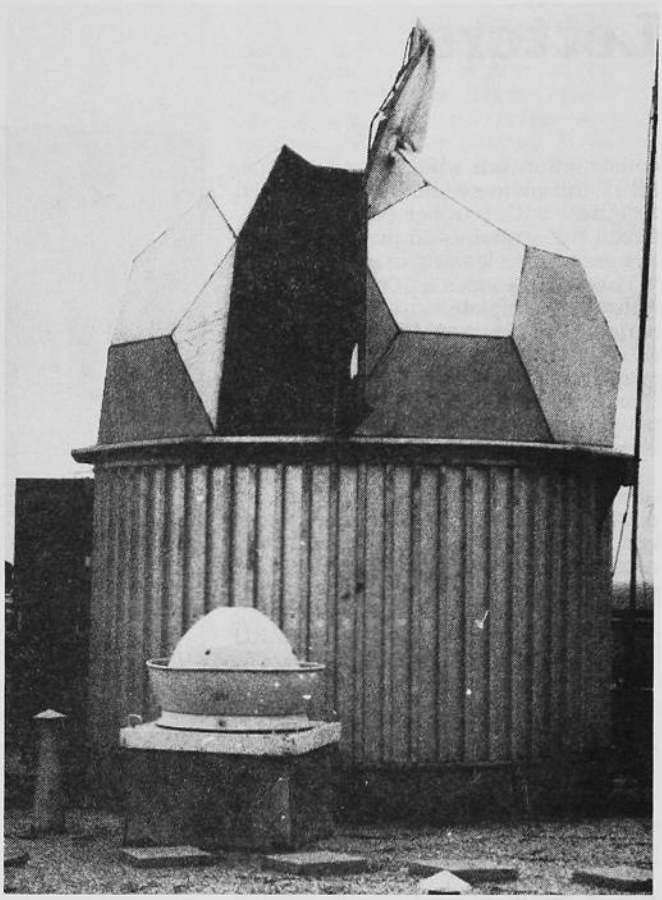
Dear Richard/ Thank you so much for writing such a fine article about our Winter Star Party. I'm sure *TM* now has a few thousand readers who will want to come to see for themselves just how fine our seeing really is. Last year was the finest on record for having the weather cooperate with our dates for the star party. Usually we only have weather that fine on the Full Moon. We should be so lucky every year!

The Winter Star Party has been blessed by the fact that we have never been clouded out completely. The year before it clouded up every night shortly after sunset, but always cleared by one or two a.m., and we were then treated to the best seeing we have ever experienced. (Yes, the seeing gets even better when the wind stops!) Many of us were doing detailed drawings of Mars, and it was only 5 arcseconds in diameter, yet the surface detail was outstanding. Don Parker and Jeff Beish were teaching us how to use colored filters, and kept changing eyepieces till they were using near 1000 power.

Last years was only the second year we used the Camp Sawyer site in the Keys, but we hope to continue to hold the Star Party there every year. The only drawback is that the site is very small, so small in fact...that about 350 people is the most it can hold. Rumor holds that the 1990 registration will be limited to the first 350 astronomers who register.

The Florida Star Party is held each year in November, at a site in northern Florida that could hold several thousand. It's held near the small town of Chiefland, about 9 hours driving time north of the Keys. This site is





80 acres that is owned by 8 astronomers—an astronomy commune if you will. Five observatories are built on the site so far. The skies are not as dark as the Texas Star Party, but close. Of course the transparency of the air is not as good as the high desert, but seeing is usually sub-arc second. The Florida Star Party is also run like the Texas Star Party is. You set up your tent and telescope on Thursday, and don't have to move anything till the star party is over on Sunday. Makes life kind of easy...if you like camping. If your readers can't make the Winter Star Party, tell them to try this one. Or better yet...try both!

You were very kind when writing about the performances of our telescopes. Everything we at Tectron Telescopes have learned, about how to make the finest performing telescopes, has come right out of the pages of *Telescope Making*. We have all the back issues, and believe me, they are well read. Anyone who is willing to read this information and use it could make a telescope that performs as well, providing they use top-notch, well-mounted optics!

By the way, Richard, I hope you know you made my wife's year. Jeannie is just thrilled to be the cover girl of *TM#36* with her 25-inch telescope! The "very thoughtful photographer" of this photo was you! I remember because I came walking around the edge of my trailer about 2 a.m. and almost ran into you and your camera while you were taking the shot. Glad I missed you.

Tom Clark
Tectron Telescopes
2111 Whitfield Park Avenue
Sarasota, Florida 34243

—Hmmm, I must have been pretty sleepy not to recognize a picture I took myself. I'm looking forward to seeing you and 348 other great observers at the 1990 Winter Star Party.

Beware of Acid Dew

Dear Richard/ Only three months after I began using my new 25-inch Dobsonian (see *TM#37*), the high-reflectivity silver coating on the mirror failed. I had hoped for better performance but apparently my very short mirror box and Wisconsin's "acid dew" were to blame. Galaxy Optics recoated it with enhanced aluminum which is still 96% reflective and much more durable. They also picked up the total cost including all shipping. I'm now using a full-length cloth shroud around the truss and I've noticed how clean and dry the primary stays. Watch out —that acid dew is bad stuff!

David Kriege
923 Stoney Road
Lake Mills, WI 53551

Graphite-Epoxy

Dear Richard/ I'd like to experiment with some graphite-epoxy compounds. Does anyone in TM-land know of a source for such materials?

Wayne Christensen
Hawaiian Astronomical Society
P.O. Box 17671
Honolulu, HI 96817

—Can any help Wayne find these materials? By the way, I've heard that graphite-epoxy compounds are tricky to handle and that they are quite toxic. Could anyone comment on this?

"Flat" Dome in Hungary

Dear Mr. Berry/ During my latest visit in Debrecen, a town in Northern Hungary, I visited its Urania Public Observatory. I was very impressed by the flat-sided dome it has, and that is why I write this letter. Your readers may be as interested in its design as I was.

The dome is located on the roof of a 20-story building, so the telescope is well above the street lights. The sky is only moderately dark, but its location suits it well for general amateur activities and public education.

The observatory dome reminded me of a soccer ball. Although the overall shape is that of a classic hemispherical dome, it is constructed using only flat surfaces. The well-planned design, attractive appearance, and the simple

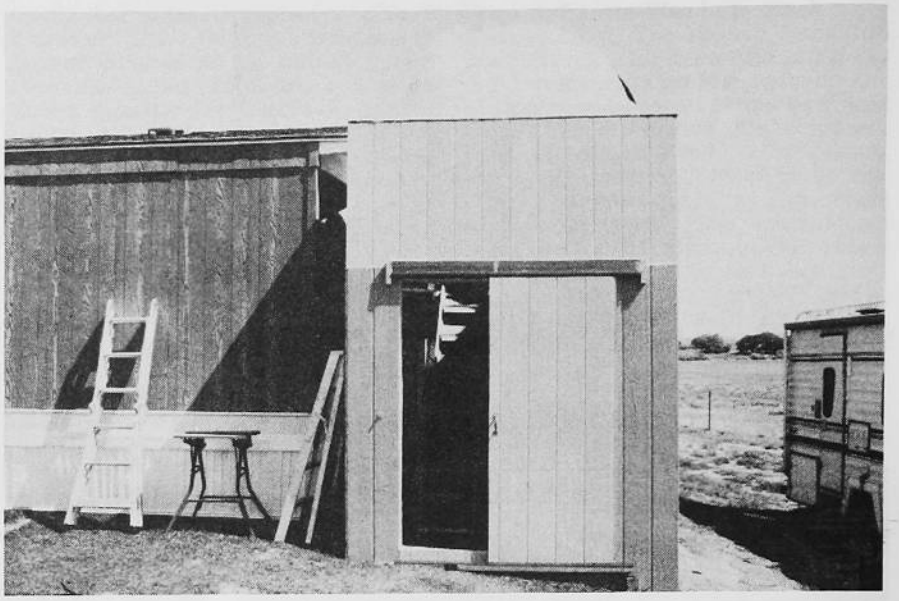
Letters

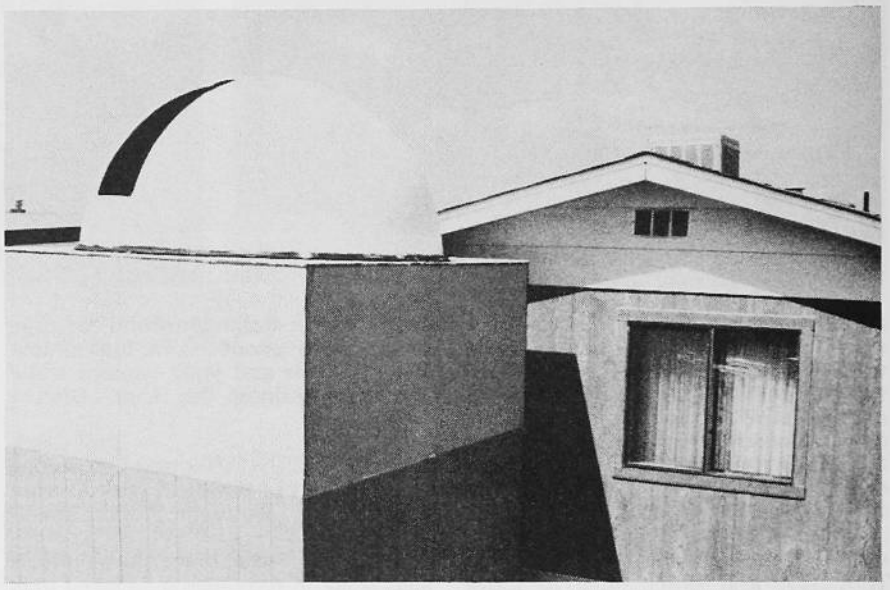
construction are what impressed me. All of the plate segments are screwed together with rubber caulking between the segments to prevent rain or the snow from leaking in.

The dome houses a 10cm f/10 Zeiss refractor complete with an eyepiece series from 4mm to 40mm, a full set of color filters, and a 4.5/250 astrograph for 9x12cm plates or sheet film. The facility has auditorium for 20 to 25 people, and a well-equipped darkroom.

After the visit I began to hesitate about the shape of my own planned observatory. Before seeing the Debrecen observatory, I would have chosen a roll-off roof design, but now I may copy the "soccer ball" dome!

Janos Papp
Code: RENRAKU
Budapest - Ujpest 1.
P.F. 161.
H-1325, Hungary





Try Tanks for Domes

Dear Sirs/ Fiberglass is cheaper, lighter and stronger than anything else available for dome—and the best way to get started is to talk to your fiberglass construction man. It'll cost you a lot to get something custom made, but of course it will fit your specifications. But if you get lucky, as I did, he may have something close to what you can use already made.

Fiberglass companies have often made something like a tank or building that is discarded for one reason or another. Maybe you'll get a discard, or something that will be just what you can use with only a few changes, for a song. Sometimes these outfits run out of space to store their material that just didn't get sold. A tank top is perfect, or a drum with an round top added.

For the last two years I have gotten good service and protection from my small dome. The weather stripping between the round dome and the square top it sits on is interlocked, and it keeps out all weather. I suggest reinforcing the round edge to help with side movement as fiberglass will spring in and out some—no problem though. On my dome, six double sets of rollers to keep dome on track and secured in right place even in high winds. Two sets of pulleys make it easy for one person to move dome around the circular hole in top observatory. Two interlocking weather strips—one on the dome and one in the observatory—keep out weather.

Dome window is weather stripped around edge and caulking on top and down sides keeps weather from running in. Four suitcase snap put pressure on stripping to seal. Two handles help in removal of window. Trap door stores ladder when in "up" position because it folds in half. This keeps the lower room clear for working. The top lid, the floor of dome, can be lowered when ladder is down to give full space of dome.

Virgil Edwards
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Evansville, KY 82636

Fixed Eyepiece Telescope

Hello Richard/ You must be happy to have new quarters. I recall the place used by Al and Sid Kalmbach when they published only the *Model Railroader* in the early 30's. Please greet them for me if either or both are still around.

I am striving to get my off-axis 16-inch Cassegrain operational with the fixed eyepiece indoors. It was intended for my "old age" but I just had my 80th birthday and the scope is not finished. In spite of an anticipated knee joint replacement, I have been observing variables regularly for the AAVSO, 500 to 800 per month, weather permitting.

Enclosed is a drawing of the scope and housing. I might add that all optical elements have provision for removable white threads intersecting at the center and on the surface of each optical element.

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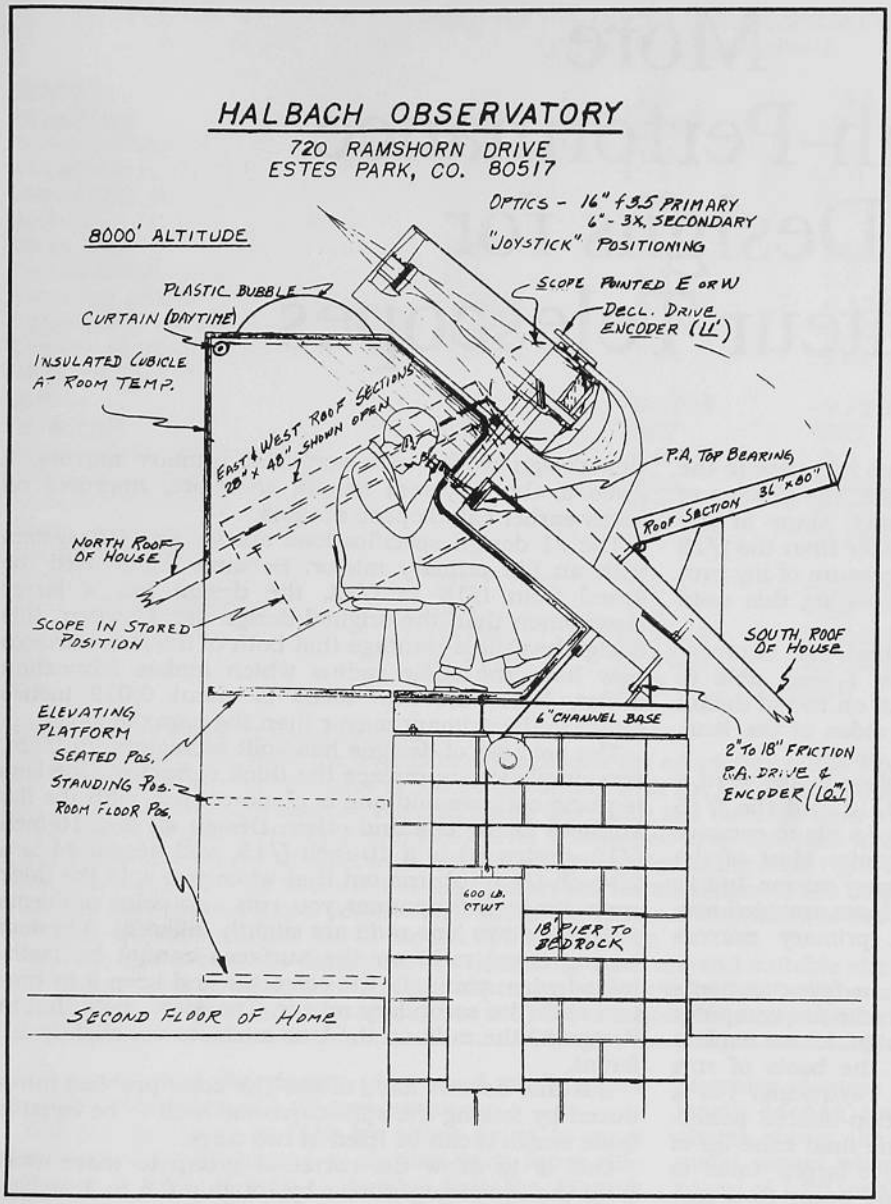

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Erica A. Becker
Office Manager

—

More High-Performance Designs for Amateur Telescopes

It has been gratifying to see so much response to the telescope design I presented in *TM#29*. The volume of mail and calls has been overwhelming. Many of you have asked for details on a design faster than the f/18 of the original instrument, but the pressure of my professional work has prevented my providing this until now.

Presented here are five designs that are improvements over the first. Not only have I been able to improve the speed to f/12 or f/15, but on two of them I have put the same radius on both sides of the lens. These originally had slightly different radii.

Because working a thick block of glass is awkward, I designed split correctors. Both the f/12 and the f/15 designs have correctors that consist of a plano-concave and plano-convex pair of lens elements. Most of the designs require an f/2 spherical primary mirror, but in the interest of better image quality I have provided several that use an f/2.5 spherical primary mirrors instead.

Before getting to the design data, a few comments about performance. For those of you who are computer enthusiasts and will raytrace the design, let me explain that this design was optimized on the basis of rms wavefront deformation, rather than raytracing. For a design in which one wishes diffraction-limited performance, this is a better way to do the final tune-up of the design. In general, it tends to give larger "tails" to the ray-aberration curves than would occur in a ray-optimization analysis.

Another point, of interest to me, but maybe not to you, is that despite its simplicity, this design is extremely hard for most computer programs to optimize. A pretty good design can be obtained almost regardless of the starting point. But the merit function has a very shallowly curved shape, so the true minimum represented by the specifications presented here is substantially better than what most automatic design software would have stopped at.

In one way this is good because it means that there is a fairly broad range of radii-and corrector-thickness combinations that give good design results. But in another way it is bad because anyone trying to adapt the design to somewhat different parameters using a computer will probably not find the true optimum and think that I am not correct in my performance claims.

At any rate, the performance is very good over a small field of view. It degrades rapidly over larger fields, but you have to remember what you are getting: freedom from making aspherics and the avoidance of making full-aperture corrector elements. In addition, because this design works with very fast primary mirrors, it gives a short system length, therefore, improves on many earlier catadioptric designs.

The #1 design specifications are for an f/12 system with an f/2 primary mirror. Because I increased the speed from f/18 to f/12, the design has a larger obstruction than the original design did. However, this design has the advantage that both of the lens surfaces now have the same radius which makes fabrication easier. Here, the best focus is about 0.012 inches closer to the primary mirror than the paraxial focus.

The next set of designs has split correctors. In them, two simple lenses replace the thick corrector. One lens is plano-concave and one is plano-convex, with the flat surfaces facing one and other. Design #2 is a 10-inch f/12, design #3 is a 10-inch f/15, and design #4 is a 20-inch f/15. It turns out that when you split the thick corrector in this manner you run into color problems unless the two lens radii are slightly different. A system having equal radii on the surfaces cannot be maintained when you split the corrector and keep it in contact with the secondary mirror. Therefore, note that in design #2 the radii on the lens surfaces are slightly different.

But this doesn't have to be. The color problem introduced by forcing the split corrector radii to be equal is quite small. It can be fixed in two ways.

One is to allow the corrector group to move away from the secondary mirror by roughly 0.5 to 1 inches. Then the radii can be made equal. Unfortunately, this results in a smaller back focus distance for a fixed focal ratio primary. To restore the distance it is necessary to move the whole corrector/secondary mirror group toward the primary mirror, introducing slightly more obscuration. In addition, the overall performance of the design degrades somewhat.

A much better way is to combine moving the corrector group away from the secondary mirror and reducing the speed of the primary mirror. Design #1 and #2 have the f/2 primary mirror, but subsequent ones are f/2.5.

Slowing the primary to f/2.5 has a lot of benefits. It becomes easier to make the mirror, the tolerances on the corrector lens become looser, and, most important, the performance of the design gets much better. The only penalties are that the finished telescope is longer and the focal ratio slower, but really not by much. The overall length is still quite short for the final focal length achieved.

Designs #3 and #4 both employ this double approach, moving the lenses away from the secondary mirror and using an f/2.5 primary. The lens radii are

SHAFER TELESCOPE SPECIFICATIONS
(All dimensions in inches.)

SYSTEM	#1	#2*	#3	#4	#5*
Focal Ratio	f/12	f/12	f/15	f/15	f/12.5
Primary diameter	10.0	10.0	10.0	20.0	20.0
.0Primary radius	-40.0	-40.0	-50.0	-100.0	-100.0
Distance to lens surface	-15.0	-14.6	-18.0	-36.0	-36.0
Glass type	BK7	BK7	BK7	BK7	BK7
Corrector diameter	2.5	2.8	2.8	5.6	5.6
Corrector radius	4.6522	6.2756	6.1281	12.2690	18.4045
Corrector thickness	-1.4033	-0.200	-0.200	-0.4	-0.400
Corrector radius	4.6522	Flat	Flat	Flat	Flat
Distance to next surface	—	-0.9768	-0.7228	-1.4526	-3.5453
Glass type	BK7	BK7	BK7	BK7	
Corrector diameter	—	2.8	2.8	5.6	5.6
Corrector radius	—	Flat	Flat	Flat	Flat
Corrector thickness	—	-0.35	-0.35	- 0.70	- 0.70
Corrector radius	—	5.9777	6.1281	12.2690	16.6146
Distance to next surface	0.0	0.0	-1.0816	- 2.3763	0.0
Secondary diameter	2.5	2.8	2.8	5.6	5.6
Secondary radius	- 10.7883	- 10.7545	- 13.0061	- 25.5473	- 26.7796
BFL	24.1170	24.1020	28.6336	55.9675	47.1189
EFL	120.0	120.0	150.0	300.0	250.0

*Radii are not equal in these designs
• In the designs 1,2,and 5 the lens is in contact with the secondary surface at the center.
• In design #5 the split corrector is placed in contact with the secondary and the BFL has been shortened as the large aperture does not need so big a BFL and the result is a faster system with a more extensive real field.
• The field stop in a 1.25- inch eyepiece barrel is assumed to be one inch in diameter.
• Light travels from left to right with a positive sign but travelling from right to left it has a negative sign. Since all distances in the list are to the left of the primary mirror all distances are therefore negative in sign.
• Radius of curvature has a positive sign when the center of curvature of the surface lies to the right of the lens apex and negative when it lies to the left of the lens apex.
• The lens and secondary diameters are their clear aperture and suitable size must be added to allow for edging and mounting of these optics. One can assume a minimum of 0.25" will be added to the clear aperture figures when figuring the obscuration amount in the best of cases. For inexperienced workers this will likely be larger.

made equal, and the design gives good performance over the field of view of 1.25-inch eyepieces.

You can get back to f/12 by either going to more obscuration, or by having a shorter back focus distance, or a little of both. I decided that the 20-inch design, design #4, could have proportionally less back focus distance than the 10-inch and worked out design #5 with a smaller BFL. In this case, you can bring the final image to the side of the tube by placing a small flat mirror in front of the primary mirror.

These telescopes all have fairly small fields of view and are intended primarily for observing the planets and other small objects. They are basically all visual telescopes. Performance is diffraction-limited over most of the visual spectrum, except for the very deep blue, over its small field of view.

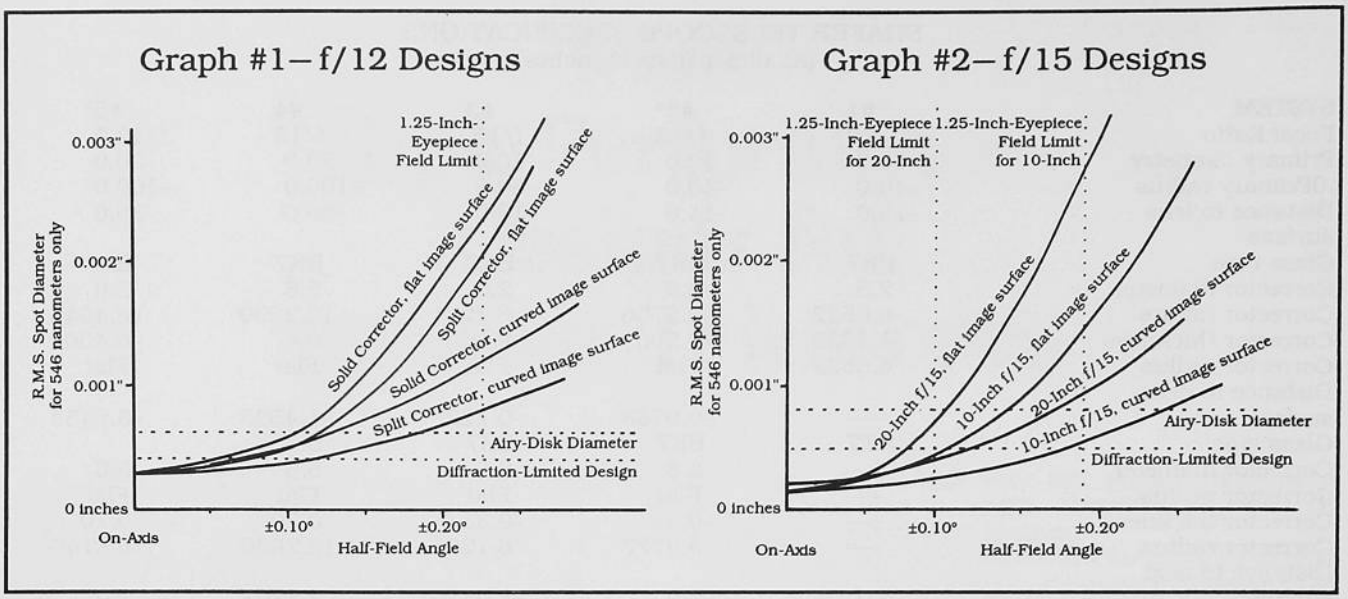
When the design is scaled up to larger apertures, the aberrations scale up too. The aberrations can be reduced enough to permit diffraction-limited performance, even in very large apertures, by scaling down the angular field of view requirement such that the linear image size remains about the same. This basically means the design performs well with a 1.25-inch eyepiece at whatever aperture you build. Scaling up requires reoptimization of the design. This explains why the 20-inch design given here is not a simple two-times scale-up of the 10-inch one.

I have prepared charts that show how the rms spot diameter changes with field angle for the single wavelength of 546 nanometers. The vertical line on the charts shows the location of the maximum field one might expect when using a low power eyepiece with a barrel of 1.25 inches. The plots show one line that gives the Airy disk diameter and another line that represents the boundary of diffraction-limited performance. It turns out that for these designs, and possibly for any design, the rms spot diameter that corresponds to a Strehl ratio of 80 percent is quite a bit smaller than the Airy disk diameter. This makes sense because the rms diameter is a weighted average of rays, some of which go quite a bit beyond that rms diameter.

These plots have some interesting information on them. The performance on a curved image surface is much better than on a flat image. The flat image curves were all done by finding the optimum focus on axis and staying with it. There was no attempt to make some compromise focus position to balance out the center versus the field.

In graph #1 for the f/12 designs, it is clear that the split corrector with unequal radii outperforms the solid corrector with equal radii. Although I haven't done it, I imagine that a solid corrector with unequal radii could do as well.

In graph #2 for the f/15 designs with a slower-speed primary mirror, it is clear that the angular field of the 20-inch primary design is smaller than the 10-inch pri-



mary design. However, the linear field size would be larger because the focal length is twice as long.

Color effects have not been included in these graphs. It turns out, however, that the split-corrector f/12 design has much better color correction for spherochromatism and lateral color than the solid corrector design. The equal-radius f/15 split corrector has about the same color performance as the f/12 unequal-radii split corrector. The 20-inch split corrector, due to its size, has about the same color performance as the 10-inch solid corrector design.

For a comparison I designed a two-mirror Ritchey-Chretien system to compare with the 20-inch design. The Ritchey had the same primary speed, the same system speed, and the same distance between the primary vertex and the final image. Both mirrors were hyperboloidal in shape.

On a flat image surface, the Ritchey-Chretien design had a diffraction-limited field diameter about 40 percent larger than my design when it was evaluated at just one color. The field was also about 40 percent larger on a curved surface. Considering the difficulty of making a 20-inch-diameter f/2.5 hyperboloid and a convex hyperboloidal secondary mirror surface, I think that the all-spherical design compares well.

My busy professional work schedule has delayed this project until now. Because the huge response from the original material in *TM#29* almost got out of hand, I would like to ask that inquiries come only from those seriously interested in these instruments.

To recap, let me repeat that with this design you get very good performance from a simple design having a short tube length, over a small field across a broad wavelength range, accomplished without aspherics and without a full-aperture corrector lens.

Dave Shafer
56 Drake Lane
Fairfield, CT 06430

Editor's Note: Since I had the privilege of presenting Dave Shafer's original f/18 design at several large gatherings of telescope makers and its subsequent appearance in *TM#29*, we received numerous inquiries about a faster system. In spite of a busy professional schedule, Dave has reworked his specifications.

I have run raytraces of his 10-inch designs (both f/12 in a solid and an air-spaced system) and have also run raytraces of the f/15 systems for the 10-inch and 20-inch designs. The program I used, Optical Systems Design Program (OSDP), is distributed by Gibson Optics, 1017 Thistle Court, Sunnyvale, CA 94086; phone (408) 739-9453. OSDP can optimize a design, although one should heed Dave's injunction to be careful with automatic optimizations.

The accompanying raytrace analysis shows that most of the field of view in an eyepiece with a 1.25-inch barrel presents good images over half the field diameter. All of Dave's study was based on a flat focal surface with optimum focus set on the optical axis. The accompanying spot diagrams shown were made for a curved field because I think the amateur is likely to focus his telescope between the edge and center to obtain the most pleasing field of view.

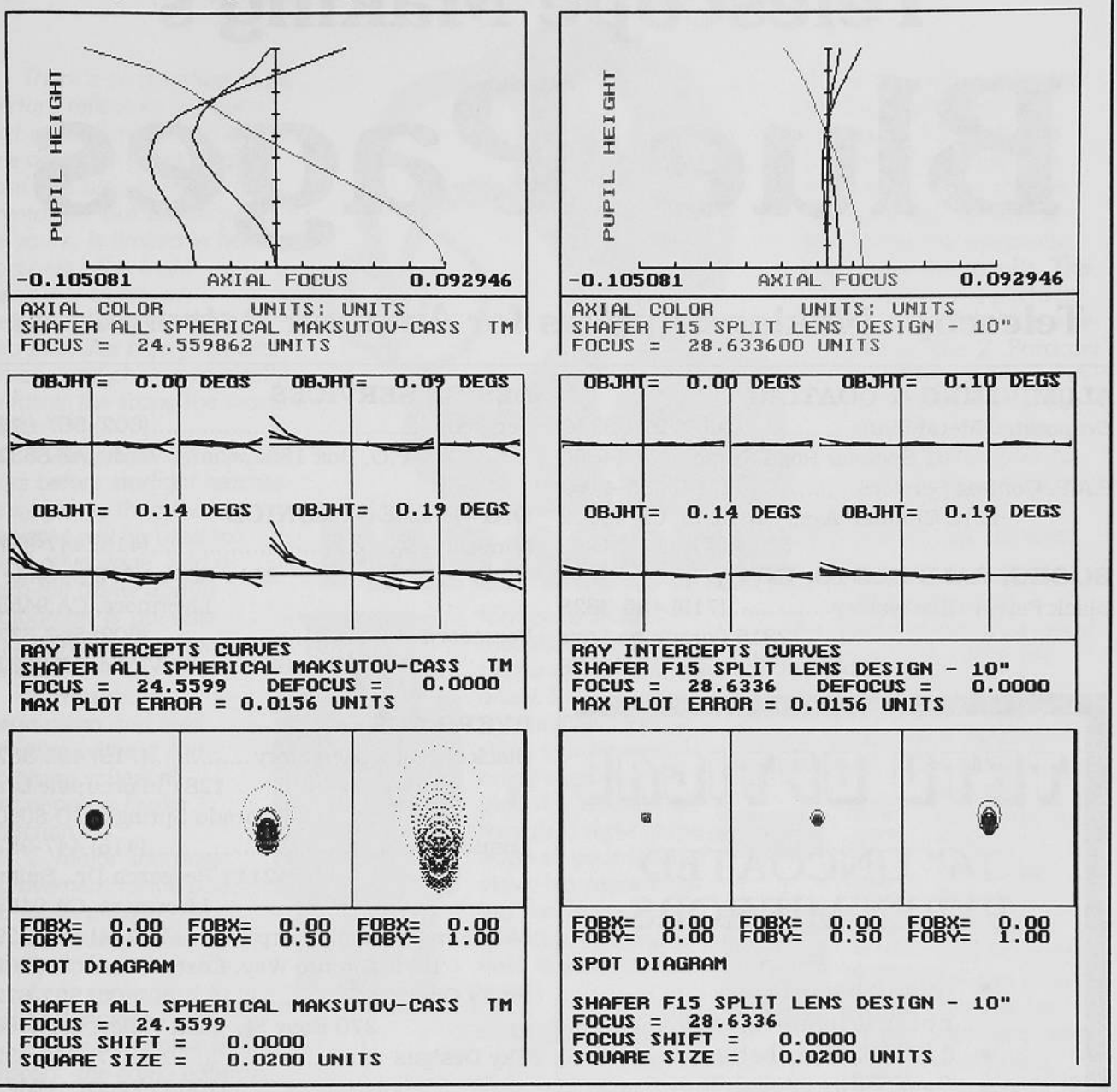
The difference in image quality between the f/12 and f/15 designs is quite obvious from the analysis programs. As Dave states in his articles, this design is well suited for planetary and lunar observing, and the f/15 design field is decidedly superior to the f/12.

The spot diagrams with a box size of 0.010 inches enable you to estimate the central blur size. Remember that the extreme rays are generally so faint that they do not appear visually. The OSDP program displays the rms image diameters for three field positions, shown in the table under the spot diagrams. Beside the spot size are figures that suggest the displacement from the BFL for the best image at these field locations.

I have also included two other interesting parameters: the size of the Airy disk and the calculated focusing tolerance for the focal ratio of the instrument. The first figure indicates how much of the light bundle formed at the focus falls inside the Airy disk. Ideally you would want all the light to be so placed. Note that these figures are quite reasonable out to 50 percent of the real field in the focal plane. As seen in the spot diagrams and indicated in the rms figures, the edges of the systems suffer from field curvature.

The figures for the shift from the axial focus to the calculated smallest image size are interesting to compare to the focusing range. The focusing range is the distance an observer can move the focuser without

Ray-Tracing the Original Shafer Design and the New Shafer Designs



noticing a degrading effect on the image. The figure given is for one direction only, from outside focus to inside focus. The focusing range is twice that given.

Note that out to 50 percent of the field radius in all of the designs, the focusing tolerance is greater than the suggested shift for the minimum spot diameter in the table. This suggests that the field curvature is lost in the focusing tolerance. The Airy disk and focusing tolerance are dependent only of the wavelength of light (546.1 nanometers is used in the analysis) and the focal ratio of the optical system.

For those who run a raytrace analysis, be sure to use the proper angular field of view of the telescope. As suggested by the above analysis, eyepieces with 2-inch barrels will not yield acceptable star images in the outer portion of the field. Most design programs ask for half the angular field of view in degrees. If the program asks for the field diameter, double the semifield figure.

In fabricating this design, make the secondary and lenses the same size to expedite mounting and aligning them, and mount them in a single tube. Be sure that the whole unit can be moved relative to the primary so that you can tweak final performance; also be sure the lens assembly can be moved relative to the secondary mirror for further help in final tweaking. In addition, I suggest placing a 1-inch-diameter field stop inside the barrel of the lowest-power eyepiece you use regularly.

These designs have not been prototyped and field tested. *Telescope Making* would be most interested to hear from anyone who fabricates one of these systems so we can present field-test results to our readers.

— Robert E. Cox

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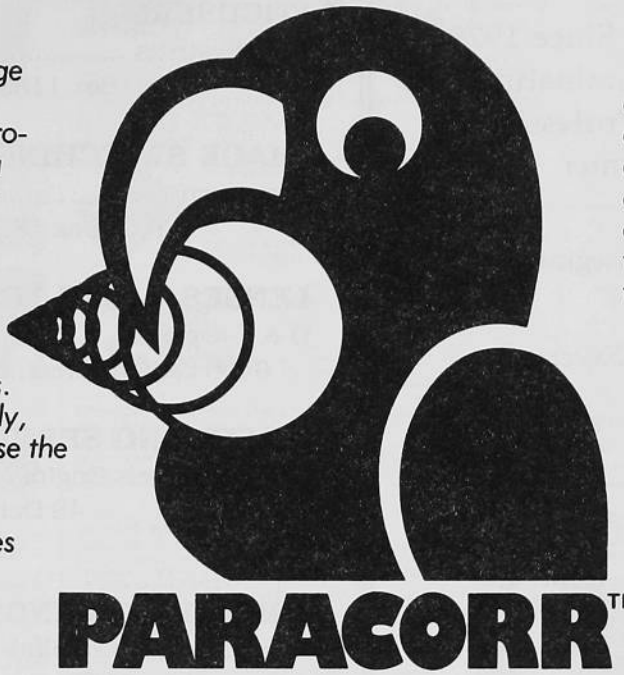

There's no question large aperture reflectors like John Vogt's excellent 30" f/3.8 produce deep sky views rivaling those I've seen in major observatories. But his scope, like yours, is limited in field sharpness. The main offender is coma, an aberration which makes stars look like blurry comets. Visually and photographically, the faster the scope the worse the effect.

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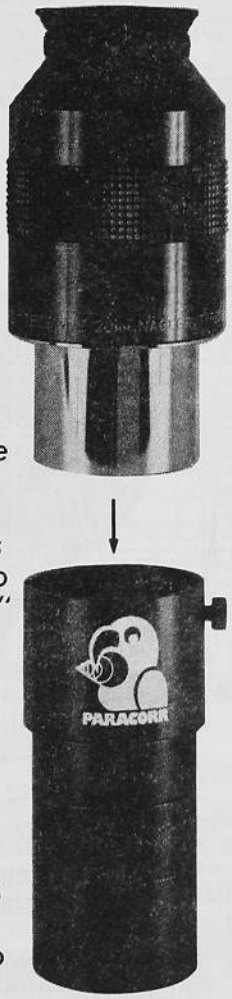
—Al Nagler



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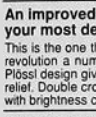

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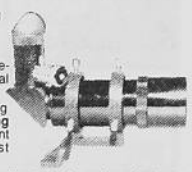

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2" right-angle version, non-rotating focuser **$199**
1¼" Deluxe right-angle Super-Finder **$279**
2" Deluxe right-angle Super-Finder **$309**
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Coma 1 inch off-axis (17½" f/4.5)

Same Field with LUMICON coma corrector lens; note smaller, more numerous stars.

This computer-designed LUMICON 2" lens reduces coma and flattens the field for both viewing and photography. It threads into LUMICON 2" EASY-GUIDERS for effortless installation. This lens is optimized for f/4.5 and reduces aberrations for f/3.5 to f/5 Newtonians. Off-axis images are much smaller, making off-axis guiding far easier and yielding round pinpoint star images in photos. Since star images are sharp over a full 2¼" circle, you can use medium format cameras in addition to 35mm cameras. This zero power lens does not change image scale nor shift focus, and all lens surfaces are multi-coated for highest efficiency. Although designed for photography you may also use this lens to improve image quality in wide-field viewing with low power eyepieces.

LUMICON Coma Corrector/Field Flattener
2" lens **$285.00**
Extension tube for viewing **$26**
2" Easy-Guider™ (state camera) .. **$169.50**

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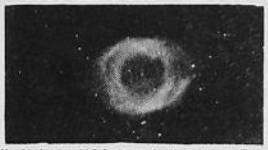
LUMICON 1.3" & 3.1" enhanced silver diagonal mirrors & 2" star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave.

1.32" **$29.95** 1.52" **$34.50** 1.83" **$39.50**
2.14" **$49.50** 2.60" **$65.00** 3.10" **$89.50**
4.25" **$149.50**

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.
1¼" (1.32" mirror) **$89.50**
2" (1.83" mirror)(see photo above) .. **$145.00**

OXYGEN-III FILTER



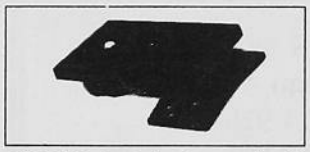
Helix Nebula, NGC 7293 in Aquarius. Bright and easy with Lumicon Oxygen-III Filter.

The ultimate in filter performance! The Lumicon Oxygen-III Filter has a contrast twice as high as the high performance Lumicon UHC Filter™. Use the Oxygen-III Filter for observing the very faintest planetary and diffuse emission nebulae. Also gives incredible views of bright nebulae (like M-27, M-17, etc.) from urban locations. Bandpass is 11nm, transmission is 90% for both O-III lines at 496nm and 501nm.

Filter Type	1¼"	48mm
Lumicon Oxygen-III	**$99.50**	**$199.50**
Lumicon UHC	**$99.50**	**$199.50**
Lumicon Deep-Sky	**$79.50**	**$119.50**
Set UHC and Oxygen-III .	**$190.00**	**$380.00**

NOTE: The Oxygen-III Filter is not a substitute, but a compliment to the UHC Filter. **1 year guarantee:** You must see nebulae with the O-III filter that are **invisible** without a filter.

NEW ADJUSTABLE PIGGYBACK MOUNT



LUMICON has just designed a new adjustable piggyback mount ideal for all telescopes of 8-14" aperture. It has **both** vertical and sideways adjustment to allow optical alignment. It was designed to allow mounting of the LUMICON SUPER-FINDER on C-8, C-14, etc., but is ideal for any telephoto lenses or small telescopes.

Deluxe Piggyback Mount **$45.00**
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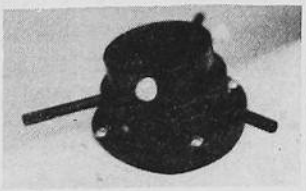

LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6" telescope.
LUMICON now offers 3 different low-profile helical focusers. They stand only 1¼-1½" above the telescope tube. Use the 1¼" or 2" versions for viewing. Use the 2" non-rotating focuser for convenient photography with the LUMICON 2" EASY-GUIDER™.
Select your desired base-plate shape!
Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 21" OD, SUPER-FINDER base plate.
LUMICON 1¼" Helical Focuser **$49.50**
LUMICON 2" Helical Focuser **$59.50**
LUMICON Non-rotating Helical Focuser $79.50
3 handles (see photo) for non-rotat. focuser **$12.95**
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†U.S. Patent 4,473,636

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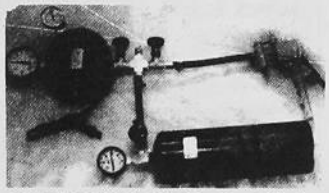

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COATING #1: 88% Reflectivity - Aluminized and quartz overcoated
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FULL THICKNESS 1:6 OPTICS

MIRROR	COATING #1	COATING #2
10"	$ 375	$ 425
12.5"	525	600
16.0"	1700	1950
18.0"	2300	★
20.0"	3400	★

LIGHTWEIGHT 2.00" THICKNESS OPTICS

MIRROR	COATING #1	COATING #2
14.5"	$ 850	1050
16.0"	1100	1350
18.0"	1300	★
20.0"	1650	★
22.0"	2970	★
25.0"	4950	★

GALAXY'S ultra-lightweight mirrors (1.6") are made from fine annealed Pyrex mirror blanks and are manufactured to the same specifications as our 1:6 mirrors.

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MIRROR	COATING #1	COATING #2
14.5"	$ 725	$ 925
16.0"	950	1200
18.0"	1100	★
20.0"	1400	★
22.0"	2450	★

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The 8" lens is very superb. The resolution, definition and contrast is way beyond our expectations.
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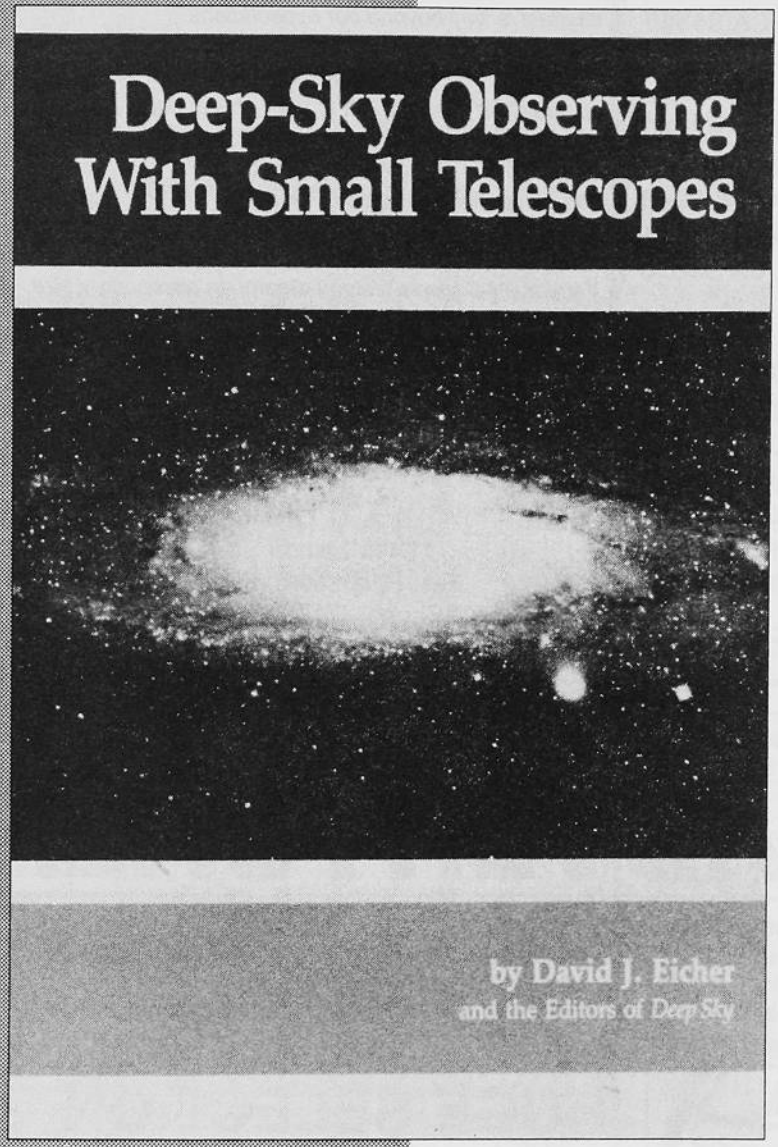

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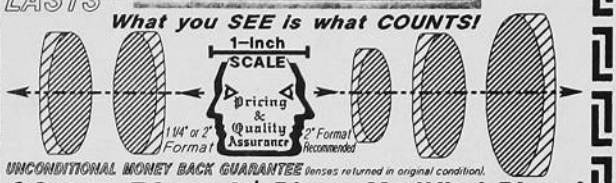

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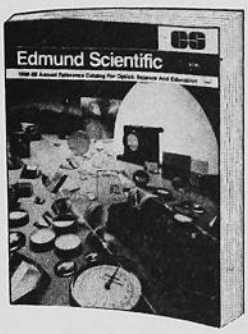

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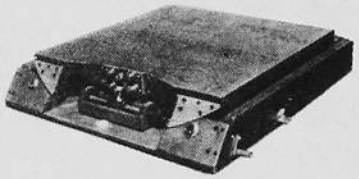

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